ANALYSIS OF THE AUGUST 14, 1980, RAINSTORM AND STORM RUNOFF TO THE SOUTH PLATTE RIVER IN THE SOUTHERN DENVER METROPOLITAN AREA, COLORADO

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 83-4138

Prepared in cooperation with the
DENVER REGIONAL COUNCIL
OF GOVERNMENTS

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IN THE SOUTHERN DENVER METROPOLITAN AREA, COLORADO

By Steven R. Blakely and Martha H. Mustard, U.S. Geological Survey;
and John T. Doerfer, Denver Regional Council of Governments

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Lakewood, Colorado

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UNITED STATES DEPARTMENT OF THE INTERIOR

WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological Survey
Box 25046, Mail Stop 415
Denver Federal Center
Lakewood, CO 80225

For sale by:

Open-File Services Section
U.S. Geological Survey, MS 306
Western Distribution Branch
Box 25425, Federal Center
Denver, CO 80225
Telephone: (303) 234-5888

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[Plates are in pocket]

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METRIC CONVERSION FACTORS

Multiply	*By*	*To obtain*
acre	0.4047	hectare
acre-inch	10.28	hectare-millimeter
acre-foot	1,233	cubic meter
cubic foot	0.02832	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
degree Celsius (°C)	(9/5°C+32)=F	degree Fahrenheit
foot	0.3048	meter
inch	25.4	millimeter
mile	1.609	kilometer
pound	0.454	kilogram
pound per acre-inch	0.04416	kilogram per hectare-millimeter
pound per cubic foot (lb/ft^3)	16,020	milligram per liter
square mile	2.590	square kilometer

average basin rainfall.--The area-weighted average of the individual rainfall quantities represented by each Thiessen polygon within that basin. Average basin rainfall is calculated by multiplying the rainfall for each polygon (which represents a rain gage) times the proportion of total basin area represented by the area of that polygon which is within the basin and by summing the resulting values.

$$\text{Average basin rainfall (inches)} = \sum_{i=1}^{n} \text{Precipitation in polygon (inches)} \times \frac{\text{Polygon}_i \text{ area in basin}}{\text{Total basin area}},$$

where n=number of polygons in the basin.

base flow.--That part of the total runoff which is not due to storm runoff.

baseload.--The quantity of a constituent that is carried by base flow. It is calculated as the product of the base flow, the base-flow concentration, and the runoff period.

convective storm.--A type of rainstorm caused by a warm, moist air mass rising through cooler air (usually due to solar warming). Subsequent adiabatic expansion cools the warm air mass to the point of saturation, and rain falls as a thundershower. A convective storm may last from a few seconds to a few hours.

detention structure.--A structure which controls the flow in a channel and which causes water to be stored temporarily, part of it being detained until the stream can safely transport the normal flow plus the released water. This detention commonly results in suspended material settling out of suspension to become part of the bed material.

effective impervious area.--An impervious area which is hydraulically connected to an improved conveyance channel or to other impervious areas which transport the runoff out of the area, such as a roof which drains onto driveways, streets, sidewalks, or paved parking lots.

event mean concentration in storm runoff.--The flow-weighted average concentration of a constituent in storm runoff. It is calculated by dividing the storm-runoff load by the storm-runoff volume.

event mean concentration in total runoff.--The flow-weighted average concentration of a constituent in the total runoff during a storm. It is calculated by dividing the total constituent load by the total runoff volume.

gaging.--Refers to the measurement of precipitation or streamflow.

ground truth.--Data collected on or near the surface of the Earth in conjunction with a remote-sensing survey. In this study, rainfall ground truth data was used to calibrate a mathematical model providing radar-simulated rainfall data.

hydrograph.--Graph of discharge versus time.

land use.--A term which relates to both the physical characteristics of the land surface and the human activities associated with the land surface.

main-stem sites.--Those monitoring sites (or stations) on the South Platte River.

National Geodetic Vertical Datum of 1929 (NGVD of 1929).--A geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada in 1929, formerly called mean sea level. NGVD of 1929 is referred to as sea level in this report.

network.--A group of gaging or sampling points located in such a manner as to allow collection of areally representative samples of the medium involved in any process (such as rainfall or runoff) occurring within a geographic region.

pervious area.--An area of porous material that allows infiltration of water, such as lawns, vacant lots, or agricultural fields.

pixel.--In a digitized image, the area represented by each digital value. In this study, a pixel refers to the smallest measurable division on the radar-reflectivity map. This division is approximately 1 square mile.

radar-simulated rainfall data.--Data that are used to indicate total rainfall quantities. These data are developed using regression equations derived from radar-reflectivity data and rain-gage data.

runoff load.--Refers to that quantity of a water-quality constituent that is transported by the storm runoff. Runoff load is calculated as total load minus the baseload during the period of storm runoff.

runoff period.--The time period from the start of a storm when runoff begins to exceed the base flow and ending with a return to base flow.

sampling.--Refers to the collection of water samples for the analysis of water properties or chemical constituents.

storm runoff.--Storm-generated surface runoff. Storm runoff is calculated as total runoff minus base flow during the runoff period.

Thiessen method.--A method for estimating the average rainfall in a basin from rainfall data collected at rain gages located in the area. The gages are plotted on a map, and lines connecting these gages are drawn. Perpendicular bisectors of these connecting lines form polygons around each rain gage. The sides of each polygon are the boundaries of the area represented by each rain gage. The area (in acres) of each polygon within the basin is determined by planimetry from the map and is expressed as a percentage of the total area of the basin. Area-weighted average rainfall for the total basin area is computed by multiplying the total rainfall measured at each rain gage by its assigned area percentage and by summing the results.

total load.--The total quantity of a constituent that is transported by the total runoff (base flow and storm runoff).

total runoff for the runoff period.--The volume of base flow and storm runoff during the runoff period. The volume of total runoff is calculated as the area under the hydrograph for the runoff period.

upslope storm.--A type of storm caused by upward movement of a warm moisture-laden mass of air when the air mass is forced up the slope of a mountain range or land mass by prevailing winds. As the warm air mass rises it expands adiabatically, its temperature decreases, and the moisture condenses into rain when the dew point is reached. Typically, an upslope storm is slower in forming and the precipitation intensity is not as great as a convective-type storm, but the upslope type often lasts longer (several hours to several days). In Denver, where prevailing winds aloft are normally westerly, upslope conditions are produced when easterly winds transporting moisture from the Gulf Coast are forced upward by the mountains on the west.

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By Steven R. Blakely, Martha H. Mustard, and John T. Doerfer

ABSTRACT

On August 14, 1980, an intense convective storm occurred over the Denver, Colo., metropolitan area. Urban runoff from this storm was monitored for both quantity and quality at three sites on the South Platte River and at one site on each of six major tributaries to the river. Tributary basins were analyzed and total areas, land use, and effective impervious areas were determined for comparison with storm-runoff loads. The total measured rainfall ranged from 0.00 to 1.41 inches. The maximum 5-minute rainfall measured was 0.37 inch.

Runoff loads were determined for total suspended solids, chemical oxygen demand, total organic carbon, and selected nutrients and trace elements. Runoff loads were calculated in pounds and pounds per acre per inch of rainfall. These loads also were computed as event mean concentrations, in milligrams per liter or in micrograms per liter, in storm runoff and in total runoff for comparison with State and Federal water-quality standards.

The effect of storm runoff on the South Platte River was to increase the volume of flow to nearly three times the base flow. The increase in main-stem runoff loads ranged from 2.6 times the baseload (total orthophosphate) to nearly 30 times the baseload (total suspended solids). The event mean concentrations of copper, lead, manganese, and zinc exceeded water-quality standards for aquatic life in Colorado at several sites monitored. The U.S. Environmental Protection Agency standards for brook trout were exceeded by copper and zinc at all sites monitored.

Further analysis of storm-runoff-load data indicates that a significant part of the main-stem storm-runoff loads may be resuspended bottom material. Also, data are compared for a tributary basin with a flow-detention structure and a similar basin without a flow-detention structure. The runoff loads from the basin with the detention structure are significantly smaller than those from the basin without flow detention.

INTRODUCTION

Increasing public awareness of the possible degradation of the Nation's water resources resulted in studies to determine point sources of pollution during the 1970's. Particular emphasis was placed on identifying these sources and assessing their impact on rivers, streams, and lakes. As these sources were identified, attention focused on nonpoint sources of pollution. This resulted in the formation of a National Urban Runoff Program by the U.S. Environmental Protection Agency.

This program had the objective of assessing the impact of urban storm-water runoff on the water quality of receiving waters. The Environmental Protection Agency selected Denver, Colo. (among others) as a representative urban environment (in a semiarid climate) and provided grant monies to the Denver Regional Council of Governments to begin an impact assessment of urban storm-water runoff.

Storm runoff can affect the quality of water in the South Platte River as a result of the trace elements and nutrients that accumulate in the environment. Little is known about the concentrations of these constituents in storm runoff to the South Platte River in Denver. Another unknown is the magnitude of nutrient and trace-metal loads that are suddenly introduced into the South Platte River by storm runoff. This effect could be significant, as the entire load is then rather quickly available to the aquatic life of the river. A study of the effect of storm runoff on the South Platte River was begun through a combined effort of the Denver Regional Council of Governments and the U.S. Geological Survey.

The data presented in this report were collected as a part of this study. The storm of August 14, 1980, was selected for this report because it was the largest of only three storms in the Denver area during 1980 and 1981 that were of sufficient size and duration and that were monitored on an intensive basis.

Purpose and Scope

The purpose of this report is to present an analysis of the August 14, 1980, rainstorm in Denver, Colo., and describe its effects on the South Platte River and six of its tributaries (fig. 1). The analysis is separated into four parts:

1. Basin characteristics are presented and discussed for tributary and main-stem sites.
2. Rainfall quantities and intensities are discussed in terms of areal distribution throughout the study area.
3. Basin characteristics, rainfall, runoff, and constituent loads are presented in tabular format and discussed.
4. Total metal concentrations are compared with current (1981) State and Federal water-quality standards.

Data-Collection Methods

A network of rain gages (pl. 1) which previously had been established in the Denver metropolitan area was used to obtain 5-minute rainfall data. The Denver Regional Council of Governments, through a contract with the Urban Drainage and Flood Control District, obtained radar-simulated rainfall data from GRD Weather Center, Inc., who generated the data using a mathematical model based on rain-gage and radar data. These simulated rainfall data have an areal resolution of about 1 square mile. Ground truth for calibration of the model was provided by rain-gage data. This information was used to obtain average basin rainfall quantities for the tributary basins and the main-stem basins.

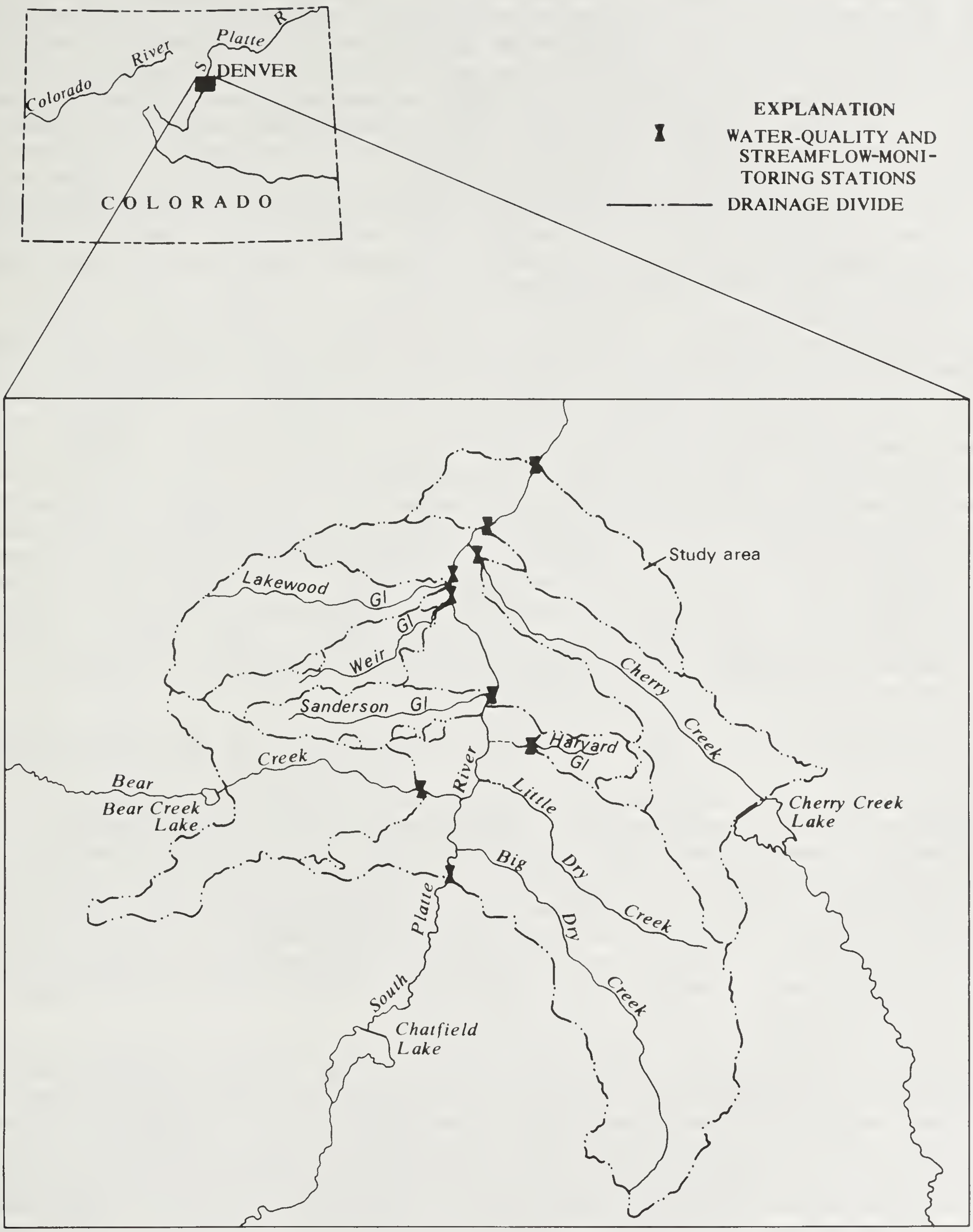

Figure 1.--Location of water-quality and streamflow-monitoring stations and study area.

A data-collection network was established to provide streamflow and water-quality information at three main-stem stations on the South Platte River and six stations on its tributaries in the Denver area. The stage at the three main-stem stations was monitored by continuous stage recorders; stage-discharge relationships for these stations were derived using current-meter measurements, channel geometry, and indirect measurements of flow. Bear Creek and Cherry Creek were monitored by continuous stage recorders. Harvard Gulch was monitored by a continuous digital stage-recorder at 5-minute intervals. Stage-discharge relationships were derived for these stations as for the main-stem stations. The remaining three tributaries--Sanderson Gulch, Weir Gulch, and Lakewood Gulch--have nonrecording gages only, and stage data were obtained visually at intervals of 5 to 15 minutes by personnel onsite during the rainstorm.

Stage-discharge rating curves for Sanderson Gulch, Weir Gulch, and Lakewood Gulch were developed using a step-backwater model (Shearman, 1976; Eichert, 1979) and were used to estimate discharge from stage observations at each of these stations. Initial curves, developed using Shearman's model, were verified against backwater interference using Eichert's HEC-2 step-backwater model. Runoff volumes were calculated for each station using the discharge data. The error inherent in computing discharges using stage-discharge curves derived by step-backwater methods is estimated to be 10 to 15 percent for most of the sites (R. D. Jarrett, U.S. Geological Survey, oral commun., 1982). Base-flow volume was separated from the total runoff volume to provide storm-runoff volume. The error in storm runoff based on this subjective separation of stormflow and base flow from a continuous recorder strip chart is estimated to be as follows: Bear Creek, ±7 percent; Cherry Creek, ±35 percent; South Platte River at 19th Street, ±17 percent; and South Platte River at 50th Avenue, ±12 percent.

Water-quality samples were collected at all stations in the streamflow-monitoring network. Six to eight samples were collected at each station during the duration of the storm-runoff period. This sampling schedule was designed to insure that changes in the streamflow water quality as a result of storm runoff would be determined at several times during the storm. At each station an attempt was made to collect one initial sample of base flow, two samples during the period of increasing discharge, one or two samples at or about the peak discharge, two samples during the period of decreasing discharge, and a final sample as close to prestorm base flow as possible. Storm loads of selected constituents were calculated from the discharge and water-quality data. These water-quality data are published in a hydrologic-data report by Gibbs and Doerfer (1982).

Tributary and main-stem drainage-basin boundaries were determined from topographic maps and surveys of the area. The area for each basin was obtained, and boundaries were marked on a map of the study area (pl. 1). This map and aerial photographs were used to estimate land uses in seven categories (Turner, 1981) for each tributary and main-stem basin. This information was obtained for use in calculating impervious areas and to aid in the comparison of rainfall, storm runoff, and runoff loads from each basin.

Topographic elevations from 7½-minute quadrangle maps of the area were used to define surface-runoff basin boundaries. A comprehensive examination was not

made of the storm sewers that route runoff between basins, but the effects were assumed to offset one another. The size and frequency of basin interflows based on onsite observations indicate that this has minimal effect on total basin storm runoff. Storm-sewer maps did not exist for some areas of the metropolitan area (in particular, the west side of the South Platte River). Drainage areas were delineated from U.S. Geological Survey 7½-minute topographic maps at 1:24,000 scale. A map of the study area showing tributary and main-stem basins and monitoring stations is shown on plate 2. Drainage areas for each of the monitored tributary and instream basins and for unmonitored areas are presented in table 1.

Land use determined for the tributaries, main-stem basins, and unmonitored areas is presented in table 1, along with the percent of total area for the land use. Low-altitude black-and-white aerial photographs at an approximate scale of 1:12,000 were used as a base for interpreting land use. The photographs were taken during an overflight of the study area on May 31 and June 1, 1980. Land-use acreage was measured to a resolution of 2.5 acres on a mylar base map placed over the aerial photographs. Definitions of each land-use category were taken from Turner (1981).

The effective impervious area within each drainage area was calculated using the characteristic values for the Denver metropolitan area presented by Alley and Veenhuis (1979). The product of the mean percent impervious area and the mean percent of that impervious area, which is effective for each land-use category, was calculated to produce an average percent effective impervious area for each land use. This value multiplied by the number of acres in a basin for a particular land use produced the number of acres of effective impervious area from that land use in each basin. These values of effective impervious areas (acres) by land use were summed to provide a total effective impervious area for each basin and unmonitored area (table 1).

An average value of impervious areas and effective impervious areas reported by Alley and Veenhuis (1979) for industrial land was computed and used even though they did not report an average because the range of values was very large. The mean effective imperviousness of land in the single-family category was calculated to be 18 percent; in the multifamily category, 54 percent; in the commercial category, 86 percent; and in the industrial category, 39 percent. Lands in the park, vacant, and agricultural-use categories were assumed to have no effective impervious areas.

The storm-runoff data and water-quality samples for five of the tributary stations were collected by the U.S. Geological Survey and analyzed by the U.S. Geological Survey's laboratory at Denver. Ambient and storm-runoff data and water-quality samples for main-stem stations and Cherry Creek were collected by the Denver Regional Council of Governments and analyzed by the Metropolitan Denver Sewage Disposal District No. 1 laboratory. Because analytical methods may differ from one laboratory to another and because two laboratories analyzed samples collected for this study, references are provided for the analytical methods used by each laboratory.

Table 1.--*Land use, total area, effective impervious area, and urbanized area for tributary and main-stem basins and unmonitored and direct-flow areas within the study area*

[Values are expressed in acres; values in parentheses are percentage of the total area. Column totals may not agree with row totals and percentages may not add to 100 percent due to rounding of values]

	Single family	Multi-family	Commercial	Industrial	Park	Vacant	Agricul-tural	Total area	Effective impervious area	Urbanized area[1]
South Platte River at Littleton-----	----------	----------	----------	----------	----------	----------	----------	----------	----------	----------
Bear Creek-------	5,240 (34)	477 (3)	1,340 (9)	318 (2)	1,430 (9)	6,510 (42)	112 (1)	15,400 (100)	2,460 (16)	7,360 (48)
Harvard Gulch----	1,290 (64)	120 (6)	380 (19)	10 (1)	160 (8)	40 (2)	0	2,000 (100)	628 (31)	1,800 (90)
Sanderson Gulch--	2,950 (62)	160 (3)	590 (13)	107 (2)	322 (7)	589 (12)	0	4,720 (100)	1,170 (25)	3,810 (81)
Weir Gulch-------	2,780 (58)	321 (7)	455 (10)	54 (1)	587 (12)	534 (11)	54 (1)	4,790 (100)	1,090 (23)	3,610 (75)
Lakewood Gulch---	5,070 (49)	628 (6)	2,400 (23)	211 (2)	457 (4)	1,670 (16)	0	10,400 (100)	3,400 (33)	8,310 (80)
Cherry Creek-----	4,630 (29)	1,930 (12)	2,510 (16)	722 (5)	2,310 (15)	3,660 (23)	0	15,800 (100)	4,300 (27)	9,840 (62)
Unmonitored area-----------	16,900 (33)	1,590 (3)	5,610 (10)	4,100 (7)	2,400 (4)	16,200 (29)	6,540 (12)	53,300 (100)	10,500 (19)	29,000 (54)
South Platte River at 19th Street---	38,900 (37)	5,230 (5)	13,300 (12)	5,520 (5)	7,670 (7)	29,200 (27)	6,710 (6)	106,400 (99)	23,500 (22)	63,700 (59)
Direct flow area-----------	5,230 (45)	1,110 (10)	2,060 (18)	1,590 (14)	950 (8)	634 (5)	0	11,600 (100)	3,930 (34)	9,990 (86)
South Platte River at 50th Avenue---	44,100 (38)	6,340 (5)	15,400 (13)	7,110 (6)	8,620 (7)	29,800 (25)	6,710 (6)	118,000 (99)	27,400 (23)	73,700 (62)

[1]Urbanized area is the sum of single-family, multifamily, commercial, and industrial areas.

The method used by the U.S. Geological Survey's laboratory for determining the total metals concentrations in water samples from Bear Creek, Harvard Gulch, Lakewood Gulch, Sanderson Gulch, and Weir Gulch was the "total recoverable" method as described in Skougstad and others (1979). Methods used to analyze samples from Cherry Creek and the main-stem sites were for "total" metals as described by the U.S. Environmental Protection Agency (1974) or by the American Public Health Association (1980).

Rain-gage data and stream-discharge data for all sites except Bear Creek and the South Platte River at 19th Street were provided by the U.S. Geological Survey. Streamflow data for these two sites were provided by the State Engineer of Colorado. Basin-characteristics data were provided by the Denver Regional Council of Governments.

Description of Study Area

The study area (fig. 1) is almost entirely within the Denver metropolitan area. It is defined by a reach of the South Platte River and its corresponding drainage area between two U.S. Geological Survey water-quality and streamflow-monitoring stations. Station 06710000 (South Platte River at Littleton) is on the upstream boundary of the study area, and station 06714130 (South Platte River at 50th Avenue, at Denver) is on the downstream boundary.

The study area extends a maximum of 23 miles in a south-to-north direction, which is also the approximate direction of flow of the South Platte River through most of Denver. The maximum breadth of the study area is about 21 miles east to west. The altitude of the study area above sea level (National Geodetic Vertical Datum of 1929) ranges from about 7,965 feet in the foothills at the western boundary and from about 6,580 feet in the High Plains at the eastern boundary to about 5,140 feet at the 50th Avenue monitoring station on the South Platte River. The altitude at the Littleton monitoring station is 5,304 feet above sea level.

The South Platte River in Denver flows within a broad alluvial flood plain situated within a piedmont basin at the edge of the Rocky Mountains. The channel bottom is mostly sand and gravel except for a few areas in which bedrock is exposed or sediment has accumulated. The length of the South Platte River between Littleton and 50th Avenue is about 15 river miles and is almost 12 miles by line-of-sight.

The study area encompasses about 120,000 acres and is approximately 62 percent urbanized. The six major tributary basins monitored in the area range in size from 2,000 to 15,800 acres, and urban development ranges from 48 to 90 percent (table 1) of their individual areas. Land uses which are considered urban are single-family residential, multifamily residential, commercial, and industrial. The remaining land-use designations not considered "urban" in terms of storm runoff are park, vacant, and agricultural lands.

MONITORING STATION AND BASIN DESCRIPTIONS

The tributary monitoring stations were located as close as possible to the mouths of the tributaries. The main-stem stations were located at existing streamflow-monitoring stations, except for the South Platte River at 50th Avenue station which was constructed for this study. Two major tributaries, Big Dry Creek and Little Dry Creek, were excluded from monitoring because of several interbasin diversions. Big Dry Creek and Little Dry Creek have total drainage areas of 12,100 acres and 11,500 acres, respectively, and together comprise 20 percent of the study area.

06710000 South Platte River at Littleton

The South Platte River at Littleton streamflow-gaging station is the upstream boundary of the study area; therefore, the total drainage-area and land-use values upstream from the gaging station are not given in table 1. Streamflow in the South Platte River in the Denver area is regulated primarily by the Chatfield Lake dam, which is approximately 5 river miles upstream from this station. Any storm runoff occurring upstream from Chatfield Lake dam would be retained in the lake and diluted, thus not affecting streamflow. The area between Chatfield Lake dam and the Littleton streamflow-gaging station could contribute a significant quantity of storm runoff during a storm. Any storm runoff at this site would be subtracted from downstream runoff values to compute net runoff from the study area for those sites. There is a continuous-recording stage monitor at this station.

06711500 Bear Creek at mouth, at Sheridan

The Bear Creek basin contains 15,400 acres between Mount Carbon Dam (locally known as Bear Creek Dam) and the streamflow-gaging station which is approximately 1.3 miles upstream from the mouth, at the town of Sheridan. The drainage area upstream from Mount Carbon Dam was considered to have an insignificant effect on urban-storm runoff because of retention in Bear Creek Lake. There is a continuous-recording stage monitor at this station.

06711575 Harvard Gulch at Harvard Park, at Denver

The Harvard Gulch contributing drainage basin contains 2,000 acres between the Highline Canal (which intercepts runoff from the entire eastern part of the Harvard Gulch drainage basin) and the Harvard Gulch streamflow-gaging station at Harvard Park. This station is located about 1 mile upstream from the mouth. There is a continuous-recording stage monitor at this station.

06711610 Sanderson Gulch at mouth, at Denver

The Sanderson Gulch basin contains 4,720 acres between the headwater divide and the monitoring site near the mouth of Sanderson Gulch. There is a nonrecording gage at this station.

06711622 Weir Gulch at mouth, at Denver

Weir Gulch basin contains 4,790 acres between the headwater divide and the monitoring station near the mouth of Weir Gulch. About 0.75 mile upstream from the mouth, Weir Gulch flows through Barnum Lake, an approximately 7.4-acre flood-control lake usually 4 feet or less deep. There is a nonrecording gage at this station.

06711800 Lakewood Gulch at mouth, at Denver

The Lakewood Gulch basin contains 10,400 acres between the headwater divide and the monitoring station near the mouth of Lakewood Gulch. There is a nonrecording gage at this station.

06713500 Cherry Creek at mouth, at Denver

The Cherry Creek basin contains 15,800 acres between Cherry Creek Dam and the Cherry Creek streamflow-gaging station 0.5 mile upstream from the mouth in downtown Denver. An unknown but probably substantial part (possibly 50 percent) of the runoff from the area east of the Highline Canal in the Cherry Creek basin is intercepted by the canal. Therefore, the contributing drainage area of Cherry Creek basin is unknown, but is something less than 15,800 acres. The data shown in tables 1 and 2 for Cherry Creek basin are based on an earlier assumption that the basin was unaffected by the canal. This information is presented only for comparison with other basins. The drainage area upstream from Cherry Creek Dam was considered to have no effect on urban storm runoff discharged to the South Platte River by Cherry Creek because there is no outflow released from Cherry Creek Dam. There is a continuous-recording stage monitor at this station.

06714000 South Platte River at 19th Street, at Denver

The South Platte River basin at 19th Street drains an area of 107,400 acres between the streamflow-gaging station at Littleton and the streamflow-gaging station at 19th Street in Denver. This basin contains all of the tributary basins and 54,300 acres of unmonitored area. There is a continuous-recording stage monitor at this station.

06714130 South Platte River at 50th Avenue, at Denver

The South Platte River basin at 50th Avenue drains an area of 118,000 acres between the streamflow-gaging station at Littleton and the streamflow-gaging station at 50th Avenue in Denver. The area between the 19th Street station and the 50th Avenue station is 11,600 acres. Runoff from this area is considered direct flow and is monitored only as the difference between the streamflow at 19th Street and the streamflow at 50th Avenue. There is a continuous-recording stage monitor at this station.

PRECIPITATION

On the afternoon of August 14, 1980, an intense convective rainstorm occurred in the Denver area, followed closely by an overnight upslope rainstorm. These storms were preceded by 4 to 6 weeks during which less than 0.15 inch of rainfall was recorded in the study area on any 1 day.

The convective storm consisted of several very intense storm cells moving across the study area (pl. 3), which produced significant runoff at the monitoring stations (pl. 2). The convective storm was characterized by significant rainfall intensities throughout a large area (pl. 4). This was the first such storm for which water-quality data were collected for the National Urban Runoff Program from major urban tributaries to the South Platte River in the Denver metropolitan area.

The upslope storm which immediately followed the convective storm lasted through the next afternoon. The areal coverage of the upslope storm was fairly uniform but the 24-hour rainfall was relatively small, ranging from about 0.2 to 0.5 inch. The runoff from the upslope storm was not monitored for three reasons: (1) The storm runoff is difficult to distinguish from the base flow when the peak discharge is small and the discharge is relatively uniform as would be expected from an upslope storm, (2) the storm-runoff loads from this particular upslope storm would not be representative of other upslope storms because the preceding convective storm had just removed much of the potential load from the basins, and (3) it is prohibitively expensive to manually monitor the runoff and water quality for more than a few hours.

The rainfall was recorded using five tipping-bucket rain gages and eighteen 3-inch pipe totalizing continuous-recording (5-minute intervals) rain gages. Precipitation graphs, rainfall-data summaries, and location of each of the rain gages are shown on plate 1. The total rainfall measured ranged from 0.00 to 1.41 inches. The duration of rainfall ranged from 0 to 150 minutes. The maximum measured 5-minute rainfall was 0.37 inch. The maximum 15-minute rainfall was 0.8 inch, and the maximum 60-minute rainfall was 1.41 inches.

GRD Weather Center, Inc., indirectly monitored the storm by recording images of radar reflection over the study area from the National Weather Service's Limon, Colo., radar transmitter transmitting at an angle of 0.5° from horizontal. The intensity of reflection of a microwave radar beam directed at a cloud is related to the size of the raindrops in the cloud which, in turn, is an indirect measure of the intensity of rain falling from the cloud (Linsley and others, 1975).

Six discrete values were used to describe the entire range of radar-reflectivity intensities and, thus, to simulate areal rainfall intensities. A discrete value was recorded every 15 minutes as an areal average for each pixel, the smallest division of the radar-reflectivity map, representing approximately 1 square mile. The recorded values are temporal averages of three sequential 5-minute values. Using an exponential curve, GRD Weather Center, Inc., made a regression analysis of these radar-reflectivity values using recorded rain-gage data to produce maps showing the simulated rainfall in each pixel for each of 12 consecutive 15-minute time increments between 1330 and 1630 hours on August 14, 1980.

Precipitation maps based on the simulated rainfall during the most intense rainfall periods (1400-1530 hours) are presented on plate 3. The 15-minute simulated quantities of rainfall from 1330 to 1630 hours were summed to produce a precipitation map for the entire storm (pl. 4) and to determine average basin rainfall (pl. 2).

Both rain-gage and radar-reflectivity data are considered essential by the authors to characterize this storm. The rain-gage data are necessary to determine accurate rainfall quantities and intensities at specific locations; however, rain-gage data alone can be misinterpreted. The Thiessen method (Linsley and others, 1975), which is one of the most common means of extrapolating point-rainfall data to an average basin rainfall, depends on linear interpolation of the data points. However, the areal variability of rainfall is not necessarily linear, especially for a convective storm such as the storm of August 14, 1980, in Denver, Colo.

The following is an example of the error involved in interpolating rain-gage data from Thiessen polygons. The calculated rainfall for Weir Gulch basin would have been 0.93 inch using the Thiessen method, whereas the basin rainfall was 0.28 inch using the more representative simulated-rainfall data derived from the radar and rain-gage data. Rainfall computed using the Thiessen method is weighted very heavily by data from the Villa Italia rain gage (pl. 1). This rain gage recorded more than twice as much rain as did any gage within 3 miles. Therefore, it is inappropriate to use data from the gage to calculate rainfall for as large an area as indicated by the Thiessen polygon. This logic is supported by the areal variability of rainfall shown by the radar data. Thus, the use of the Thiessen method alone will not provide sufficiently accurate resolution of rainfall information.

Analysis of rainfall information can be significantly enhanced by the use of radar-generated rainfall data. The average basin rainfall determined for each basin from Thiessen polygons and from radar-simulation methods is compared in table 2. The addition of radar data provides a better estimate of the areal distribution of rainfall than rain-gage data alone. Linear interpolation is not necessary because radar data of sufficient resolution for this study are recorded on a uniform grid. Furthermore, the value of each pixel is an average value of all the data within each pixel, not just the value of a single point within the pixel.

There are some disadvantages in using radar data. One is that radar data are not sufficient to determine rainfall directly because there is no universal factor that can be applied to the radar data to convert them to rainfall data. The radar-rainfall data relationship needs to be determined for each storm. Another disadvantage is that there are spatial and temporal differences between the rain falling from the cloud as determined by radar and the rain measured at the ground (Linsley and others, 1975). These differences are considered negligible in this report. A third disadvantage of using recorded radar reflectivity in this manner is that the values assumed to represent a temporal average of three sequential 5-minute values may be in error when normal scanning is interrupted. During the August 14, 1980, storm, the National Weather Service used the Limon transmitter to

Table 2.--*Comparison of average basin rainfall for the storm of August 14, 1980, for tributary and main-stem basins as determined by the Thiessen polygon method and the radar-simulation method*

[Rainfall in inches]

Basin	Thiessen polygon method	Radar-simulation method
Bear Creek-------------------------	0.33	0.31
Harvard Gulch----------------------	.69	.33
Sanderson Gulch--------------------	.39	.32
Weir Gulch-------------------------	.93	.28
Lakewood Gulch---------------------	.54	.22
Cherry Creek-----------------------	.53	.29
South Platte River at 19th Street--	.59	.27
South Platte River at 50th Avenue--	.56	.27

scan the clouds for hail and tornadoes. This was done by altering the angle of transmission. Reflectivity values recorded during this process were eliminated from the data base; however, GRD Weather Center, Inc., always assumed there were three values to be averaged in the data-management system. Therefore, the average radar-reflectivity values were probably underestimated. For the purposes of this report, such errors were assumed to be negligible.

BASIN CHARACTERISTICS, RUNOFF, AND RUNOFF LOADS

Total area, effective impervious area, rainfall, total runoff, storm runoff, and the storm runoff-rainfall ratio for each of the monitored tributaries and for the 19th Street and 50th Avenue main-stem stations are presented in table 3. The rainfall data given for each basin are considered representative of the rainfall which occurred in that basin. The runoff volumes and the runoff-rainfall ratios are believed to be representative of the storm conditions of August 14, 1980, for Harvard Gulch, Bear Creek, Sanderson Gulch, and the 19th Street and 50th Avenue stations. All tables of runoff and of storm loads are presented in the order of increasing total area rather than in downstream order to aid in data comparisons based on basin characteristics. All runoff and load values given for the main-stem stations were computed by subtracting values observed at the South Platte River at Littleton station unless the difference was negligible or within the range of systematic and rounding error (±5 percent).

Table 3.--*Total area, effective impervious area, rainfall, total runoff, storm runoff, and runoff-rainfall ratios for tributary and main-stem stations from the storm of August 14, 1980*

[Runoff in inches is normalized to total basin area; rainfall is the radar-simulated rainfall basin average]

Data category	Harvard Gulch	Sanderson Gulch	Weir Gulch	Lakewood Gulch[1]	Bear Creek	Cherry Creek[2]	South Platte River At 19th Street	South Platte River At 50th Avenue
Total area (acres)----	2,000	4,720	4,790	10,400	15,400	15,800	106,400	119,000
Effective impervious area (acres)----	628	1,170	1,090	3,400	2,460	4,300	23,500	27,400
Effective impervious area (percent)--	31	25	23	33	16	27	22	23
Rainfall (inches)---	.33	.32	.28	.22	.31	.29	.27	.27
Total runoff (million cubic feet)	1.2	1.4	.99	.68	4.0	5.2	41	60
Storm runoff (million cubic feet)	1.2	1.3	.92	.64	2.7	4.2	27	39
Storm runoff (inches)---	.165	.075	.053	.017	.048	.073	.070	.089
Storm runoff/ rainfall ratio (inches per inch expressed as percent)	50	23	19	7.7	15	25	26	33

[1]See discussion of Lakewood Gulch data.
[2]See discussion of Cherry Creek data.

Data presented for Cherry Creek are qualified by the effect of the Highline Canal, an irrigation canal which traverses Harvard Gulch and Cherry Creek in a northeasterly direction (pl. 1). At the beginning of the project it was assumed that the Highline Canal had no effect on the volume of storm runoff occurring in the basins it traversed. However, recent visual inspection reveals that it intercepts runoff from the entire eastern part of Harvard Gulch basin and a large proportion of the eastern part of Cherry Creek basin. The Harvard Gulch data were revised, but an exact determination of the effect in Cherry Creek basin would require an engineering survey which is beyond the scope of this project.

The Cherry Creek data on runoff volumes and storm loads are accurate to the extent that they show what Cherry Creek delivered to the South Platte River at the mouth on August 14, 1980. The information shown in tables 1 and 3 regarding contributing drainage area (total area) for Cherry Creek basin is too large by an undetermined area. The information regarding storm runoff (and runoff in inches) may be less than the actual values by as much as 27 percent or 1.55 million cubic feet of storm runoff. As much as one-half and possibly more (R. L. Rosendale, Highline Canal Ditch Superintendent, Denver Water Board, oral commun., 1982) depending on the storm intensity of the storm runoff in Cherry Creek basin east of the canal is intercepted and transported out of the basin by the canal. The area in Cherry Creek basin east of the canal is 54 percent of the total Cherry Creek area. Thus, it is estimated that at least 27 percent of the storm runoff and possibly more is transported out of the Cherry Creek basin by the Highline Canal.

The uncertainty involved in evaluating the magnitude of Cherry Creek storm runoff and loads with regard to total and effective impervious area precludes making any conclusive statements of comparison with other basins. It is apparent that the values given for total and effective impervious area for Cherry Creek basin downstream from Cherry Creek Dam (54 percent of which is east of the Highline Canal) are large due to the known but unquantified effect on these areas of the Highline Canal, and further that the values given for rainfall and runoff, in inches, are therefore of limited value. Any subsequent discussion and comparison of runoff and loads involving Cherry Creek data need to be considered with this qualification in mind. There also are qualifications to the runoff volumes and runoff-rainfall ratios shown in table 3 for Weir and Lakewood Gulches because flow in the gulches may have been detained.

Storm hydrographs for each monitored tributary and for the main-stem stations are presented in downstream order in figures 2, 3, and 4 to evaluate temporal and geographic effects on loading. A graph of total suspended-solids load for each station is presented with the hydrograph for a comparison of loads for the tributary and main-stem stations.

Harvard Gulch received the greatest rainfall (0.33 inch) and delivered the greatest unit storm runoff (0.165 inch). Sanderson Gulch received the next greatest rainfall (0.32 inch) and delivered the next greatest unit runoff of the tributaries monitored (0.075 inch). Weir Gulch received almost the same rainfall (0.28 inch) as did Cherry Creek (0.29 inch), but the runoff from Weir Gulch was only 0.053 inch compared with 0.073 inch from Cherry Creek--a comparison qualified by the earlier discussion on Cherry Creek. This may have been due to the detention effect of Barnum Lake and possibly to the relatively small effective impervious

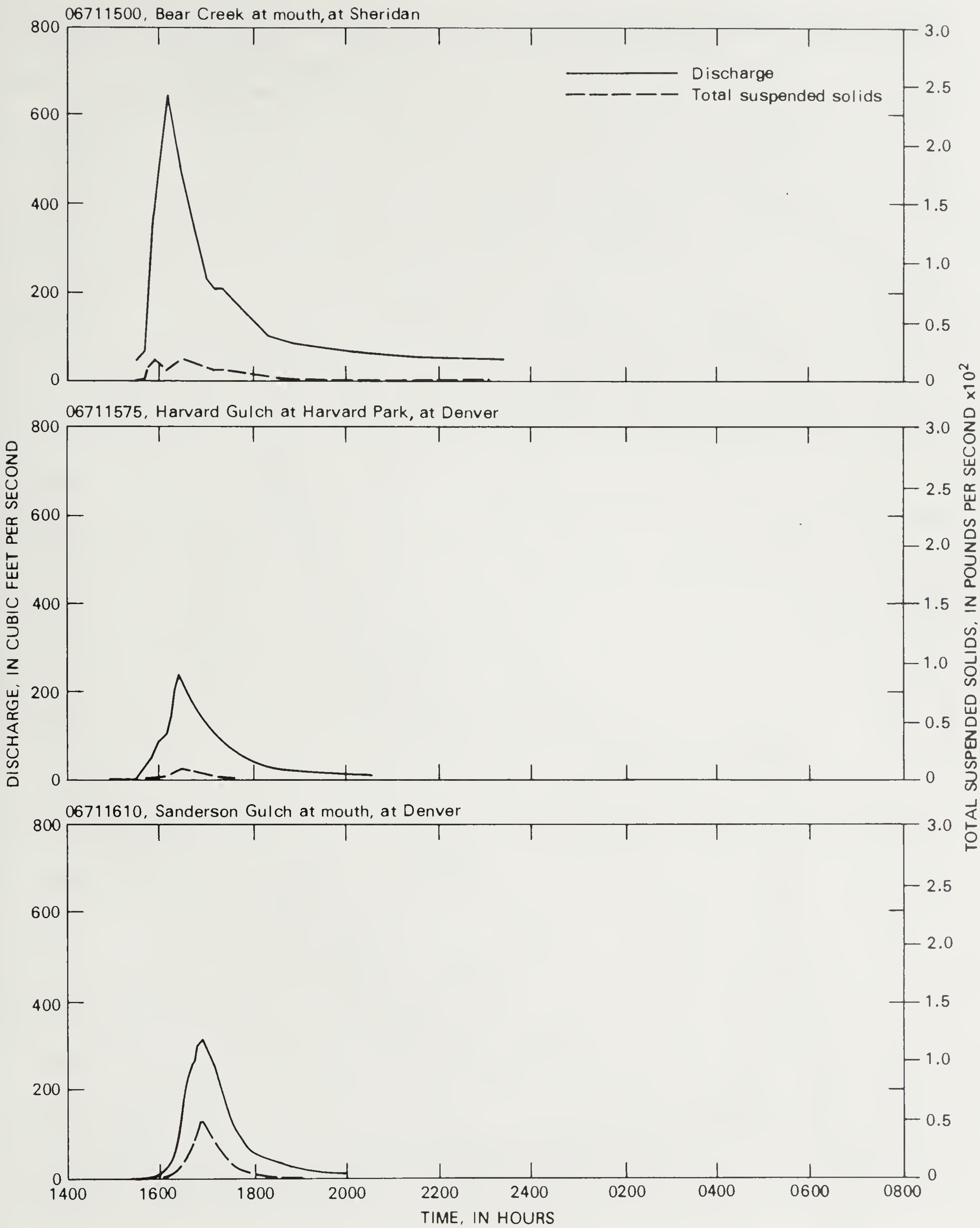

Figure 2.--Discharge and loads of total suspended solids versus time at Bear Creek, Harvard Gulch, and Sanderson Gulch during the storm of August 14, 1980.

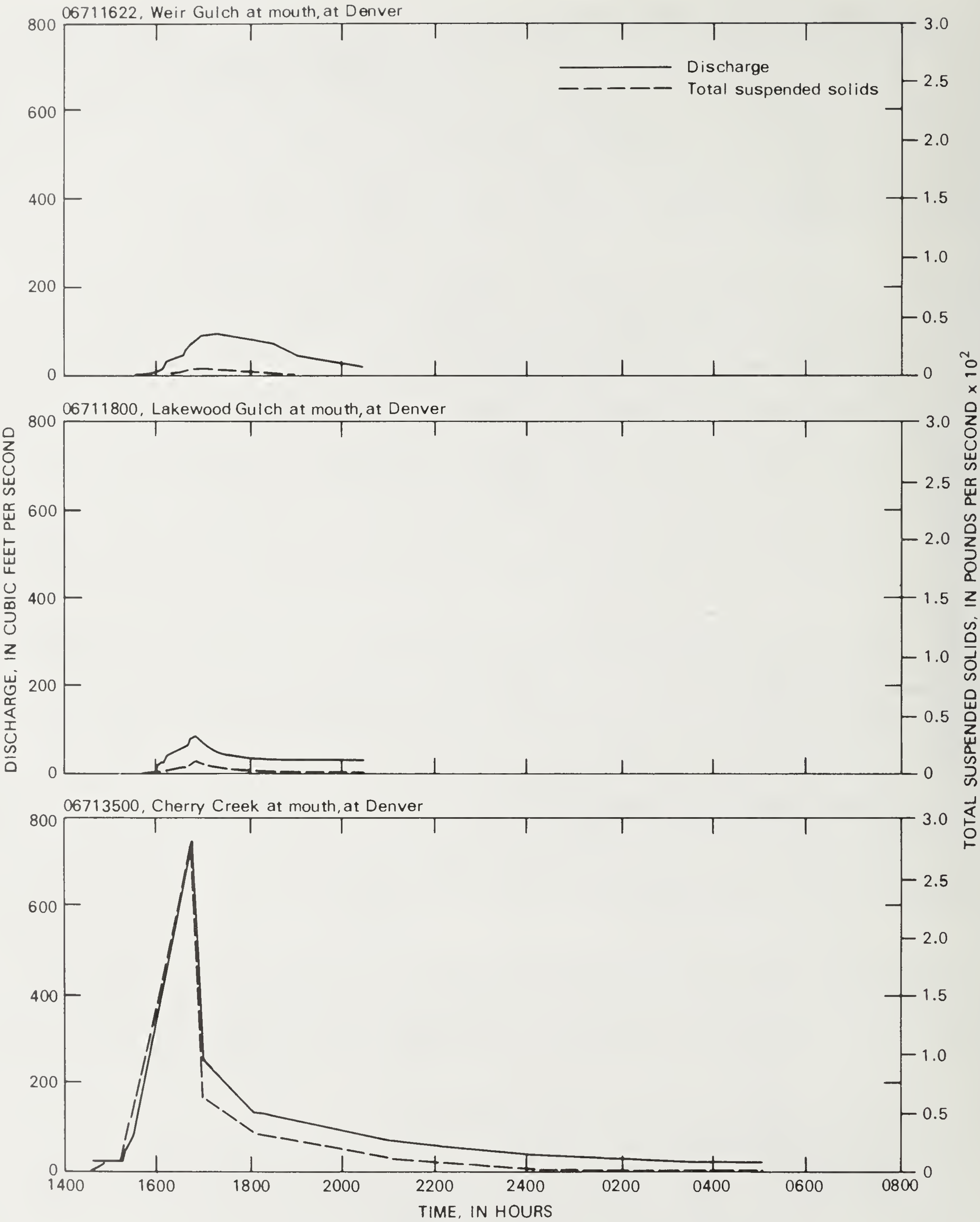

Figure 3.--Discharge and loads of total suspended solids versus time at Weir Gulch, Lakewood Gulch and Cherry Creek during the storm of August 14, 1980.

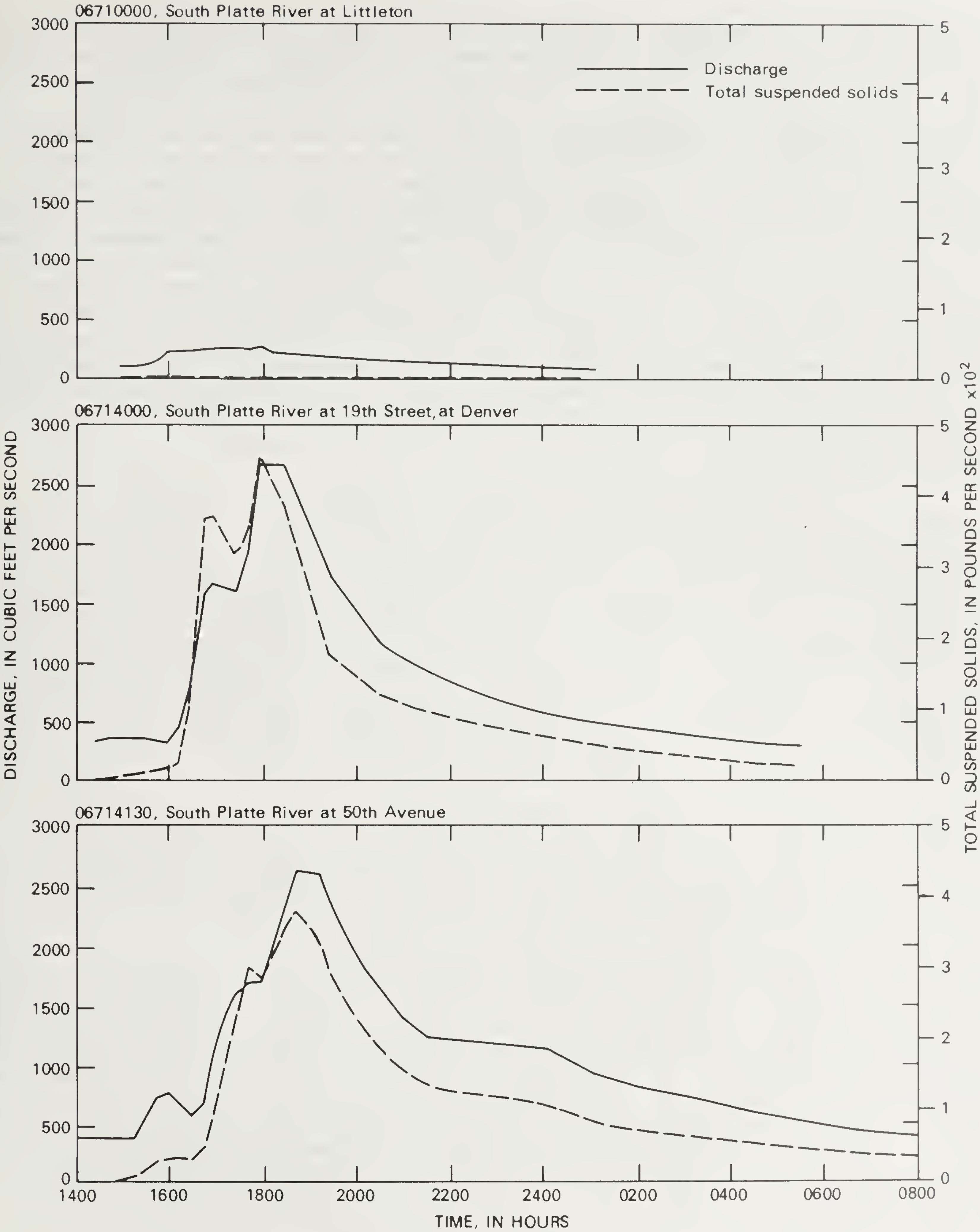

Figure 4.--Discharge and loads of total suspended solids versus time at the main stem stations: South Platte River at Littleton, South Platte River at 19th Street, and South Platte River at 50th Avenue during the storm of August 14, 1980.

area in Weir Gulch. The hydrograph of the storm runoff for Weir Gulch (fig. 3) is more attenuated than the hydrographs for other tributaries. It is low and relatively flat, a characteristic of streams controlled by flow-detention structures.

The hydrograph for Lakewood Gulch (fig. 3) shows the discharge for Lakewood Gulch did not return to base-flow levels during the monitoring period. Therefore, the total runoff and storm runoff given for Lakewood Gulch is not considered representative of the total storm data for this site. Judging from the hydrograph (fig. 3) and runoff in inches (table 3) for Lakewood Gulch, there seems to be an unknown source of detention of flow in Lakewood Gulch. An estimated 1.6 million cubic feet of storm runoff for Lakewood Gulch was calculated using an average of the runoff/rainfall ratios for the other three tributary basins on the west side of the study area [(1.6 million cubic feet = 0.19 (inches of runoff)/(inches of rain) X 0.22 (inch of rain) X 10,400 (acres) X 3,630 cubic feet per acre-inch)]. This is 2.5 times the value shown in table 3 which was calculated from the hydrograph shown in figure 3. The value in table 3 is provided only for comparison with other tributary data as an indication of the minimum magnitude of runoff in Lakewood Gulch.

Runoff from the Bear Creek basin was least (0.048 inch), even though it received the third greatest rainfall (0.31 inch); this probably is due to the small effective impervious area in the basin (16 percent). Rainfall for the South Platte River at 19th Street basin and the South Platte River at 50th Avenue basin was the same (0.27 inch), but the runoff was significantly different (0.070 and 0.089 inch, respectively). This is due to the relatively large percentage of direct-flow storm runoff entering the South Platte River between the 19th Street and the 50th Avenue gages (31 percent), compared with the percentage of drainage area (9.7 percent) between the 19th Street and the 50th Avenue gages. This large volume of runoff probably is related to the large effective impervious area (34 percent) in the drainage area between the 19th Street and the 50th Avenue gages.

The runoff-to-rainfall ratio for this storm (table 3) expressed as percent appears to be similar to the percent effective impervious area for the Bear Creek, Sanderson Gulch, and Cherry Creek basins. The differences are less than 2 percent. This relationship is within 4 percent for Weir Gulch and for the 19th Street station. However, it may only be fortuitous that these values are so similar. The relationship is not as similar for the Harvard Gulch station or the 50th Avenue station where the percent runoff/rainfall substantially exceeds the percent effective impervious area (50 percent versus 31 percent and 33 percent versus 23 percent, respectively). This probably is due to the unusually large direct flow to the South Platte River downstream from the 19th Street gage discussed earlier and the possible error inherent in computing an effective impervious area for an area which has the greatest percentage of industrial land use. This could easily account for an underestimated effective impervious area from 19th Street to 50th Avenue. Some additional error in runoff values may have been introduced from the subjective separation of the 50th Avenue hydrograph into its base-flow and stormflow components.

There also is a possibility that main-stem flow may have been significantly increased by inflow of approximately 200 and 100 cubic feet per second of storm runoff spilled into Big and Little Dry Creeks, respectively (R. L. Rosendale, Highline Canal Ditch Superintendent, Denver Water Board, oral commun., 1982), from the Highline Canal during the storm. The total volume of this inflow is estimated to be as much as 4.1 million cubic feet (94 acre-feet; 10.5 percent of the storm runoff at the 50th Avenue gage). When the capacity of the canal is exceeded, or when the canal contains no water (which was the case on August 14, 1980), a gate is opened and the excess water flows into Big and Little Dry Creeks, both of which are located in one of the unmonitored areas in this study.

Storm-runoff loads of the tributaries shown in table 4 were calculated using constituent concentrations and storm runoff. Therefore, the values of the storm loads shown for Weir and Lakewood Gulches and Cherry Creek are subject to the same qualifications noted earlier for the runoff volumes for those stations.

Table 4.--*Storm-runoff loads for tributaries monitored during the storm of August 14, 1980*

[Loads in pounds]

Constituent	Harvard Gulch	Sanderson Gulch	Weir Gulch[1]	Lakewood Gulch[2]	Bear Creek	Cherry Creek[3]
Total suspended solids----------	32,000	140,000	52,000	59,000	120,000	1,400,000
Chemical oxygen demand----------	11,000	26,000	10,000	14,000	22,000	120,000
Total organic carbon----------	2,300	6,000	3,000	3,400	7,200	41,000
Total nitrogen----	300	810	320	240	680	2,800
Total Kjeldahl nitrogen--------	280	770	280	210	500	2,800
Total phosphorus--	37	170	55	78	130	1,100
Total orthophosphate-----	11	12	4.2	4.5	18	42
Total copper------	2.0	10	5.1	9.2	8.2	90
Total lead--------	25	75	31	26	51	300
Total manganese---	44	170	78	89	120	650
Total zinc--------	20	61	30	38	68	440

[1]See discussion of Weir Gulch data.
[2]See discussion of Lakewood Gulch data.
[3]See discussion of Cherry Creek data.

Sanderson Gulch transported a suspended-solids load almost three times that of Weir Gulch, which is nearly equivalent in total area and effective impervious area. All the constituent loads in Sanderson Gulch were about two to three times the load computed for Weir Gulch. This comparison and the attenuated storm-runoff peak for Weir Gulch (fig. 3) indicate that Barnum Lake has considerable effect on the runoff load from Weir Gulch.

If an estimated runoff of 1.6 million cubic feet were used to compute the suspended-solids load of Lakewood Gulch, the estimated load would be 148,000 pounds, or about 2.5 times the value in table 4. This estimated load represents an approximate upper limit for the suspended-solids load of Lakewood Gulch during this storm.

Of the tributaries, Cherry Creek had the greatest total and constituent loads. Loads from Cherry Creek ranged from 2.3 to more than 10 times the loads computed for either Sanderson Gulch or Bear Creek. Cherry Creek basin is only slightly larger than Bear Creek basin, but has 1.75 times the effective impervious area if one disregards the unmeasured effect of the Highline Canal mentioned earlier. The Cherry Creek basin is 3.35 times larger than the Sanderson Gulch basin and has 3.7 times the impervious area. The last two comments regarding Cherry Creek are an understatement of the probable relationship for Cherry Creek basin statistics and are included here only to provide an illustration of the "natural" basin comparisons. The effect of the Highline Canal actually makes the comparison with other basins even more extreme.

The relatively large loads in Cherry Creek probably are the result of extensive channel modification, which was in progress during the summer of 1980. The storm-runoff quantity from Cherry Creek is representative of a smaller area than originally believed, and the storm loads presented are believed to have been greater than what normally would have been computed for Cherry Creek. The loads computed for Harvard Gulch, Sanderson Gulch, and Bear Creek are believed to be representative for those basins. Loads shown for Weir Gulch and Lakewood Gulch probably are less than actual loads for the reasons discussed earlier. Cherry Creek loads which represent a smaller area than originally thought are believed to be greater than what the undisturbed basin and channel usually would deliver from a storm of this magnitude.

Storm-runoff loads, normalized to inches of rainfall and total area for tributary and main-stem stations, are shown in table 5. It was hoped that this analysis of the data would decrease the great variability in loads between basins. The limitations on loads because of qualified runoff quantities stated earlier are still obvious here. However, an average of the five tributary values (excluding Lakewood Gulch) for total lead (0.038 pound per acre-inch of rain) is quite similar to the values for the South Platte River at 19th Street and the South Platte River at 50th Avenue (0.038 and 0.039 pound per acre-inch). Other constituents have a much greater range of values, and this comparison may be subject to greater differences. Given the qualifications stated earlier for Weir Gulch, Lakewood Gulch, and Cherry Creek, the loads presented in table 5 indicate the relative magnitude of loads that could be expected from a similar storm in areas of similar size, climate, and land use.

Table 5.--*Normalized storm-runoff loads for tributary and main-stem stations on the South Platte River for the storm of August 14, 1980*

[Storm-runoff loads are normalized to inches of rainfall and total area; units are pounds per acre-inch of rainfall]

Constituent	Harvard Gulch	Sanderson Gulch	Weir Gulch[1]	Lakewood Gulch[2]	Bear Creek	Cherry Creek[3]	South Platte River	
							At 19th Street	At 50th Avenue
Total suspended solids--------------	48	93	39	26	24	300	210	220
Chemical oxygen demand--------------	17	17	7.5	6.7	4.6	26	20	26
Total organic carbon--	3.5	4.0	2.2	1.5	1.5	9.0	6.1	7.6
Total nitrogen--------	.45	.54	.24	.11	.14	.62	.74	1.0
Total Kjeldahl nitrogen------------	.42	.51	.21	.096	.10	.61	.67	.90
Total phosphorus------	.056	.11	.041	.035	.028	.24	.24	.28
Total orthophosphate--	.017	.0079	.003	.002	.004	.009	.012	.019
Total copper----------	.003	.0066	.004	.004	.002	.020	.011	.014
Total lead------------	.039	.050	.023	.012	.010	.067	.038	.039
Total manganese-------	.069	.11	.058	.040	.025	.14	.13	.14
Total zinc------------	.031	.040	.022	.017	.014	.096	.054	.060

[1]See discussion of Weir Gulch data.
[2]See discussion of Lakewood Gulch data.
[3]See discussion of Cherry Creek data.

Under conditions of complete and adequate monitoring and sampling of runoff from a storm of this type, one would reasonably expect to be able to extrapolate storm loads based on basin characteristics and land use. Because of the incomplete data for Lakewood Gulch, the possible attenuation of loads in Weir Gulch, and the large loads for Cherry Creek, it is not possible to make any definitive extrapolation of loads to different basin sizes based on rainfall or runoff.

The basin characteristics, total and storm runoff, and storm loads for the tributaries have been summarized and are shown in table 6 under "Monitored tributaries." These values also are presented in table 6 as a percentage of the value presented in table 7 under storm loads for the South Platte River at 19th Street and the South Platte River at 50th Avenue.

Table 6.--*Basin characteristics, total runoff, storm runoff, and storm-runoff loads for the monitored tributary area, and percentage of value obtained for the South Platte River at 19th Street and the South Platte River at 50th Avenue for the storm of August 14, 1980*

[Area in acres; runoff in millions of cubic feet; constituents in pounds]

	Total value for monitored tributaries	Monitored tributary value (percent of main-stem values) South Platte River	
		At 19th Street	At 50th Avenue
Total area	53,100	50	45
Effective impervious area	13,000	55	47
Urbanized area	34,700	54	47
Total runoff	13	32	22
Storm runoff	11	41	28
Total suspended solids	1,800,000	30	26
Chemical oxygen demand	200,000	34	24
Total organic carbon	63,000	37	26
Total nitrogen	5,200	25	16
Total Kjeldahl nitrogen	4,800	25	16
Total phosphorus	1,600	24	18
Total orthophosphate	92	29	16
Total copper	120	38	27
Total lead	510	46	42
Total manganese	1,200	32	27
Total zinc	660	41	35

Table 7.--*Base flow, base-flow loads, storm runoff, and storm-runoff loads of the South Platte River at 19th Street and the South Platte River at 50th Avenue from the storm of August 14, 1980*

[Area in acres; flow in millions of cubic feet; constituents in pounds. Loads have been adjusted for loads calculated for South Platte River at Littleton]

	South Platte River			
	At 19th Street		At 50th Avenue	
Total area	106,400		118,000	
Effective impervious area	23,500		27,400	
Urbanized area	63,700		73,700	
	Base flow	Storm runoff	Base flow	Storm runoff
Flow	14	27	21	39
Total suspended solids	210,000	5,900,000	240,000	6,900,000
Chemical oxygen demand	26,000	580,000	33,000	840,000
Total organic carbon	8,100	170,000	9,400	240,000
Total nitrogen	2,900	21,000	3,000	32,000
Total Kjeldahl nitrogen	1,900	19,000	1,600	29,000
Total phosphorus	450	6,700	500	9,100
Total orthophosphate	260	320	230	590
Total copper	14	320	16	450
Total lead	27	1,100	140	1,200
Total manganese	240	3,700	390	4,400
Total zinc	81	1,600	270	1,900

The data in table 6 indicate that a substantial part of the loads at the 19th Street gage and the 50th Avenue gage may have been resuspended by scour from the bottom of the South Platte River. This possibility is based on the assumption that the load from the unmonitored area, which is 50 percent of the total drainage area upstream from the 19th Street gage, is proportional to the load from the monitored area. For example, because the monitored area contributed 30 percent of the storm load of total suspended solids at the 19th Street gage, and assuming the unmonitored area also would have contributed 30 percent, resuspended bottom material would probably account for the remaining 40 percent of the total load at the 19th Street gage, or about 2.4 million pounds. By this same logic, as much as 50 percent of the total nitrogen and total phosphorus but only 8 percent of the total lead and 18 percent of the total zinc in the load at the 19th Street gage would be resuspended bottom material. (The value for lead may be questionable

because it is approximately that of analytical error for the lead determination.) The quantity of hypothetically resuspended material estimated here is based only on total area. Seventy-three percent of the industrial land use and 42 percent of the commercial land use for the entire study are in the unmonitored area. The assumptions made here regarding the load from the unmonitored area do not include this imbalance in land-use distribution. Additional data and information would be necessary in order to make definitive conclusions about the source of storm-runoff loads in the South Platte River. The possibilities of load sources indicated by the data from this major storm point out the need for additional information regarding nonpoint sources.

It should be stated that the previous discussion of resuspended bottom material is only a possibility indicated by the data. Even if resuspension is a fact, the magnitude of resuspended material indicated here is subject to the potential error inherent in: Analytical methods (±5 percent); discharge estimations from stage-discharge curves (±10 to 15 percent); and separation of storm-runoff volumes from base-flow volumes (±7 to 35 percent). Definitive conclusions regarding instream load sources can be made only after additional monitoring.

The relatively large percentage of total storm runoff and storm-runoff load entering the South Platte River between the 19th Street and the 50th Avenue gages is believed to be related to the large percentage of effective impervious area (34 percent) and to the fact that this direct-flow area also has the greatest percentage of industrial land-use area (14 percent) (table 1). The area between the 19th Street and the 50th Avenue gages accounts for only 9.7 percent of the study area but contains 22 percent of the industrial land-use area. In contrast, the monitored area accounts for 50 percent of the study area and 21 percent of the industrial land-use area. Only 3 percent of the monitored area is characterized as industrial land-use areas.

Base-flow loads and storm-runoff loads of the South Platte River at the 19th Street and 50th Avenue gages are shown in table 7. The effect of the storm runoff on the water quality is shown by a comparison of base-flow loads and storm-runoff loads. Total orthophosphate was affected least; storm-runoff loads were 1.2 and 2.6 times the baseflow load at the 19th Street and the 50th Avenue gages, respectively.

Total orthophosphate concentrations in base-flow samples of August 14, 1980, collected at the 19th Street and 50th Avenue gages were anomalously large, exceeding the storm-runoff concentrations. Therefore, concentrations of total orthophosphate in base-flow samples taken August 5, 1980, at main-stem stations, were used as base-flow concentrations for the August 14 storm in order to obtain a more consistent and reasonable representation of base-flow conditions. The difference in concentrations between the August 5 samples and the August 14 samples for all constituents other than total orthophosphate is within the range of analytical error.

The storm-runoff loads of total suspended solids were 28 to 29 times the base-flow loads at both sites. The total lead storm-runoff load was 41 times the base-flow load at the 19th Street gage, but only 8.6 times the base-flow load at the 50th Avenue gage. All other storm-runoff loads were from 7 to 28 times the base-flow loads.

EVENT MEAN CONCENTRATIONS AND WATER-QUALITY STANDARDS

Event mean concentrations were calculated, in milligrams per liter, from the total storm-runoff load, in pounds, divided by the runoff, in cubic feet, for all constituents determined in this study and are presented in tables 8 and 9. The event mean concentrations for copper, lead, manganese, and zinc calculated for all stations in this study exceeded Colorado water-quality standards for aquatic life in effect during the August 14, 1980, storm.

The water-quality standards for aquatic life (Colorado Water Quality Control Commission, Colorado Department of Health, 1979) for constituents (total concentrations) monitored in this study were: Copper, 10 μg/L (micrograms per liter); lead, 25 μg/L; manganese, 1,000 μg/L; and zinc, 50 μg/L. The standards apply where hardness concentrations are greater than 100 mg/L (milligrams per liter) and less than 200 mg/L as $CaCO_3$. The mean hardness concentration at the South Platte River at Littleton is 145 mg/L with a standard deviation of 43 mg/L based on approximately 2 years of monthly water-quality data. These standards were written for aquatic life and include warm- and cold-water biota (inhabitants, including trout, of waters where temperatures do not normally exceed 20° Celsius). Daily maximum water temperatures at the South Platte River at Littleton were 20° Celsius or more for over 100 days during the 1980 water year. Subsequent State water-quality standards, promulgated April 6, 1981, and effective June 1, 1981 (Colorado Water Quality Control Commission, Colorado Department of Health, 1981, p. 50), increased the copper limit to 25 μg/L and the zinc limit to 110 μg/L. Both concentrations still were exceeded by the calculated event mean concentrations for both storm and total runoff in this study. The event mean concentrations of copper and zinc in both the storm and total runoff (tables 8 and 9) exceed the flow-through bioassay criteria for brook trout (10 micrograms for copper and 61 micrograms for zinc) in water-quality standards published by the U.S. Environmental Protection Agency (1976) at all stations monitored in this study.

Because Bear Creek and the South Platte River are known to support a variety of fish populations, the approximate length of time that State water-quality standards were exceeded at those stations is listed in table 10. This information was obtained from plots of dissolved-metal and dissolved-solids concentrations and discharge versus time for each of those stations, as shown in figures 5, 6, and 7. Ranges and mean values of specific conductance, ranges and median values of pH in storm runoff, and number of storm-runoff samples collected on August 14, 1980, are given in table 11 for each sampling station. All specific-conductance and pH data are laboratory values with the exception of pH for the South Platte River at Littleton, at 19th Street, and at 50th Avenue, and the Cherry Creek stations; pH was determined at these stations at the time of sampling.

Table 8.--*Event mean concentrations of selected constituents and properties in storm runoff from the tributary and main-stem stations on the South Platte River for the storm of August 14, 1980*

[mg/L=milligrams per liter; µg/L=micrograms per liter]

Constituent	Harvard Gulch	Sanderson Gulch	Weir Gulch	Lakewood Gulch[1]	Bear Creek	Cherry Creek	South Platte River	
							At 19th Street	At 50th Avenue
Total suspended solids (mg/L)------	446	1,700	911	1,500	690	5,200	3,500	2,900
Chemical oxygen demand (mg/L)------	156	330	180	360	130	450	340	350
Total organic carbon (mg/L)-------------	32	74	51	85	48	160	100	100
Total nitrogen (mg/L)-------------	4.2	10	5.6	6.1	4.0	11	12	13
Total Kjeldahl nitrogen (mg/L)----	3.8	9.6	5.0	5.3	3.0	11	11	12
Total phosphorus (mg/L)-------------	.51	2.1	.96	1.9	.80	4.3	4.0	3.8
Total orthophosphate (mg/L)-------------	.16	.14	.08	.11	.11	.16	.19	.26
Total copper (µg/L)--	30	130	100	220	50	320	190	190
Total lead (µg/L)----	350	930	540	660	300	1,200	640	510
Total manganese (µg/L)-------------	610	2,100	1,400	2,200	740	2,400	2,200	1,900
Total zinc (µg/L)----	270	750	510	960	420	1,600	960	800

[1]See discussion of Lakewood data.

Table 9.--*Event mean concentrations of selected constituents and properties in total runoff from the tributary and main-stem stations on the South Platte River for the storm of August 14, 1980*

[mg/L=milligrams per liter; μg/L=micrograms per liter]

Constituent	Harvard Gulch	Sanderson Gulch	Weir Gulch	Lakewood Gulch[1]	Bear Creek	Cherry Creek	South Platte River At 19th Street	South Platte River At 50th Avenue
Total suspended solids (mg/L)------	430	1,700	930	1,400	510	4,300	2,400	1,900
Chemical oxygen demand (mg/L)------	150	320	190	340	110	380	240	240
Total organic carbon (mg/L)-------------	32	73	56	82	36	130	71	68
Total nitrogen (mg/L)-------------	4.1	10	6.5	6.4	3.9	10	9.4	9.4
Total Kjeldahl nitrogen (mg/L)----	3.8	9.3	5.5	5.3	2.8	9.3	8.2	8.2
Total phosphorus (mg/L)-------------	.52	2.1	1.0	1.9	.60	3.8	2.8	2.6
Total orthophosphate (mg/L)-------------	.18	.14	.07	.11	.07	.25	.23	.23
Total copper (μg/L)--	30	120	90	220	40	290	130	130
Total lead (μg/L)----	330	880	570	610	210	950	440	370
Total manganese (μg/L)-------------	590	2,000	1,800	2,100	540	2,000	1,500	1,300
Total zinc (μg/L)----	260	720	550	900	290	1,400	640	580

[1]See discussion of Lakewood data.

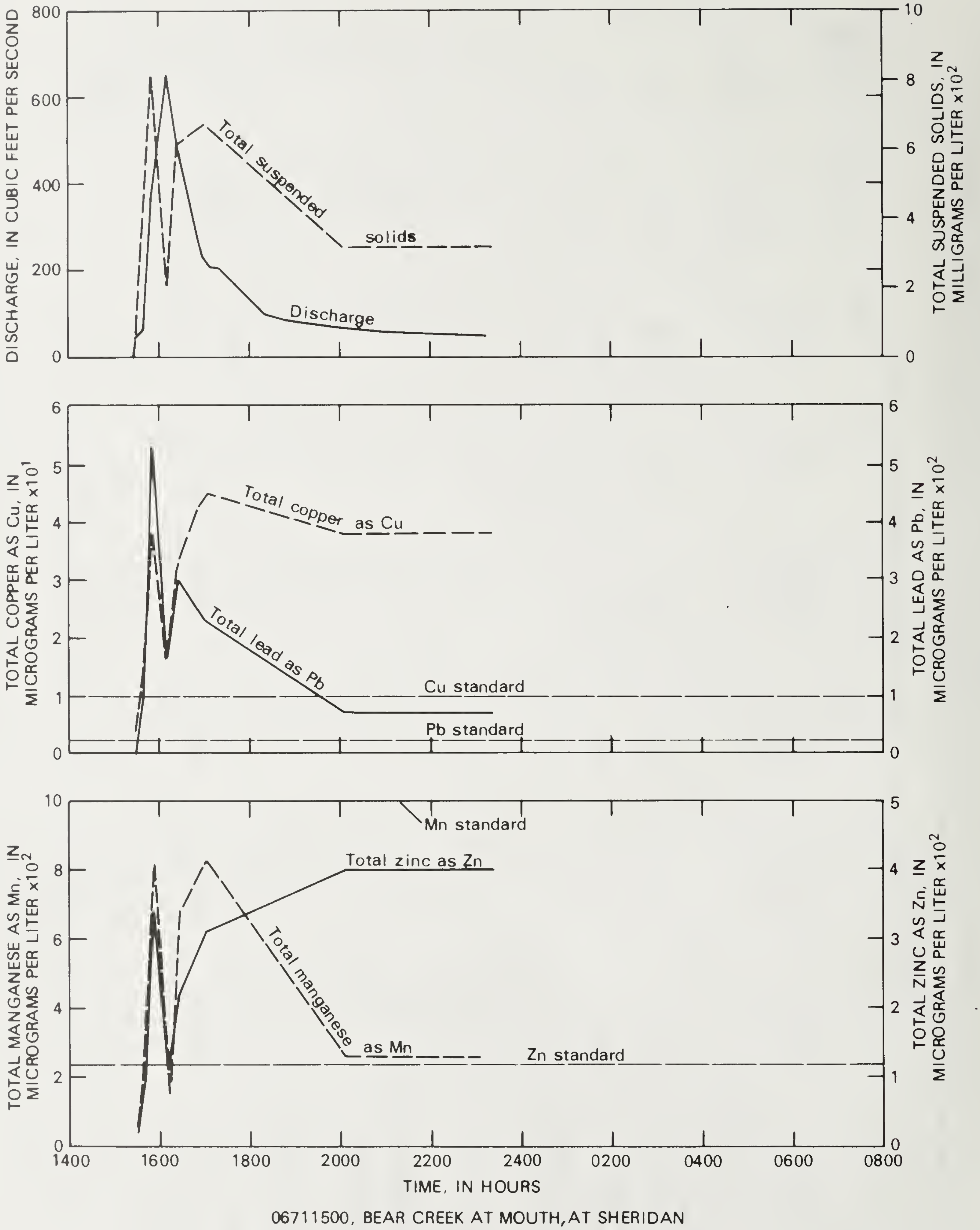

Figure 5.--Discharge and concentrations of total suspended solids and selected metals versus time at Bear Creek, at mouth, at Sheridan during the storm of August 14, 1980.

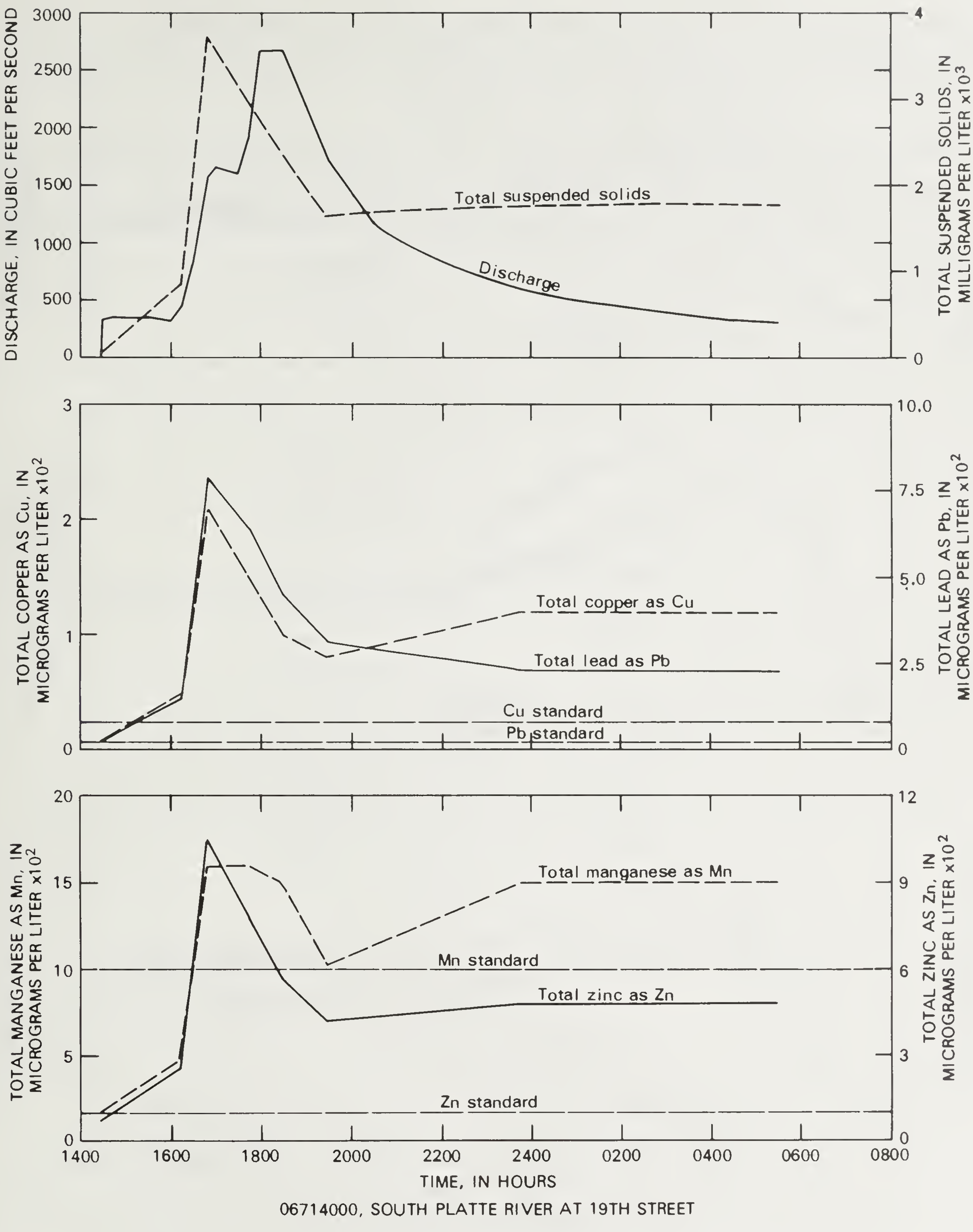

Figure 6.--Discharge and concentrations of total suspended solids and selected metals versus time at the South Platte River at 19th Street during the storm of August 14, 1980.

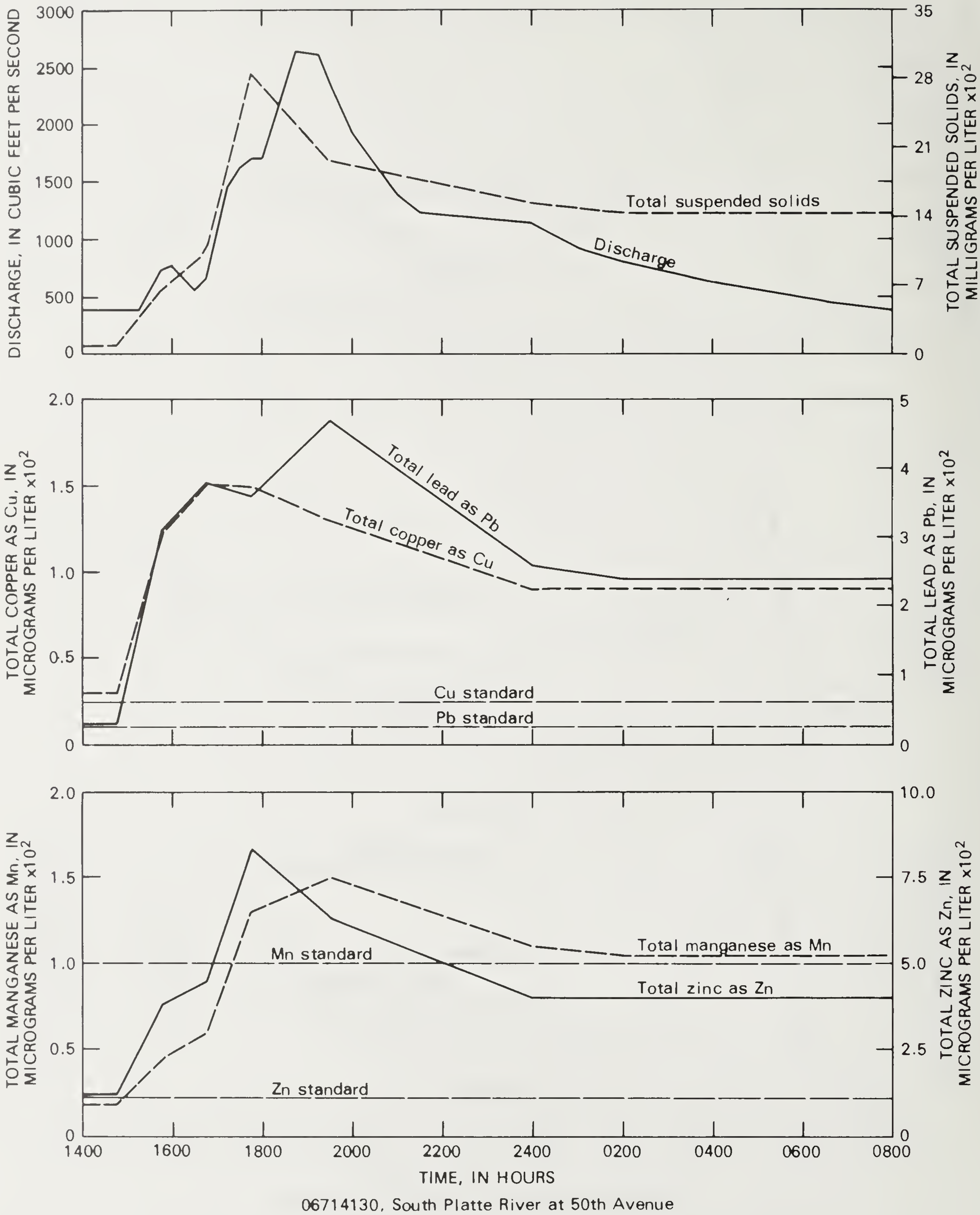

Figure 7.--Discharge and concentrations of total suspended solids and selected metals versus time at the South Platte River at 50th Avenue during the storm of August 14, 1980.

Table 10.--*Minimum number of hours that concentrations of selected metals exceeded Colorado water-quality standards for aquatic life at streamflow-gaging stations on Bear Creek and on the South Platte River during the storm of August 14, 1980*

[Based on standards adopted May 16, 1981. Limits, in micrograms per liter, for Bear Creek are: Copper, 10; lead, 25; manganese, 1,000; and zinc, 120. Limits, in micrograms per liter, for the South Platte River, from Littleton to 50th Avenue, are: Copper, 25; lead, 25; manganese, 1,000; and zinc, 110]

Selected metals	Number of hours concentrations exceeded standards
Bear Creek at mouth	
Copper---------	>7.7
Lead-----------	>7.8
Manganese------	.0
Zinc-----------	>7.8
South Platte River at 19th Street	
Copper---------	>14.5
Lead-----------	>15
Manganese------	>13
Zinc-----------	>14.8
South Platte River at 50th Avenue	
Copper---------	>18
Lead-----------	>18
Manganese------	>14.5
Zinc-----------	>18

Table 11.--*Specific conductance and pH in storm-runoff samples collected during the storm of August 14, 1980*

[Values were determined in the laboratory. μmhos/cm=micromhos per centimeter at 25° Celsius. pH units were corrected to 25° Celsius]

Station	Specific conductance (μmhos/cm)			pH (units)			Number of samples collected
	Maximum	Minimum	Mean	Maximum	Minimum	Mean	
South Platte River at Littleton[1]----	470	450	---	7.6	7.4	---	2
Bear Creek-------	450	190	300	8.4	7.7	8.0	7
Harvard Gulch----	820	160	300	8.2	6.7	7.4	8
Sanderson Gulch--	810	160	400	9.0	7.8	8.4	7
Weir Gulch-------	900	250	430	8.0	7.5	7.8	6
Lakewood Gulch---	930	240	460	8.6	7.8	8.2	7
Cherry Creek-----	1,040	260	460	8.4	7.5	8.05	7
South Platte River at 19th Street---	610	330	430	7.9	7.1	7.5	7
South Platte River at 50th Avenue---	610	350	410	7.7	6.9	7.3	7

[1]Mean and median values are not reported because only two samples were taken during the storm.

SUMMARY

Storm runoff can be detrimental to the water quality of the South Platte River when trace elements and nutrients which have accumulated in the Denver metropolitan area are flushed into the river by storm runoff. The objective of this report was to assess the effect of urban storm runoff from a major rainstorm of large areal extent on the quality of water of the South Platte River in Denver, Colo.

On the afternoon of August 14, 1980, an intense convective storm of broad areal coverage occurred in the Denver metropolitan area. Total measured rainfall ranged from 0.00 to 1.41 inches at 23 rain gages, the maximum duration of rainfall at any one rain gage was 2.5 hours, and the maximum 5-minute rainfall was 0.37 inch.

The rainstorm was monitored by radar at 15-minute intervals. The relationship between the radar data and the rain-gage data was used to obtain radar-simulated rainfall data for the entire study area. The radar-simulated rainfall data were used to prepare a precipitation map for the entire storm and individual precipitation maps for six consecutive 15-minute intervals of the most intense rainfall.

The intensity of rainfall from this storm was so variable that rain-gage data alone could not provide adequate definition of the areal distribution of rainfall. The radar-simulated rainfall data provided the areal coverage and resolution necessary to obtain estimates of basin rainfall. However, rain-gage data were used to determine rainfall intensities and to provide known values of rainfall for correlation with the radar data.

Urban runoff from this storm was monitored for quantity and quality at six major tributaries and at three main-stem stations on the South Platte River. Total areas, land use, and effective impervious areas were determined for comparison with storm runoff and storm-runoff loads.

The study area is a reach of the South Platte River between the Littleton and the 50th Avenue gaging stations and has a drainage area of nearly 120,000 acres. Forty-five percent of this study area was monitored for tributary storm runoff. Tributary basins range in size from 2,000 to 15,800 acres. Land use in the tributary basins ranged from 37 to 72 percent residential (single family and multifamily), from 11 to 25 percent commercial and industrial, and from 10 to 52 percent open space (park, vacant, and agricultural). Effective impervious area, which was calculated for each basin from land-use data, ranged from 16 to 33 percent of the tributary drainage area.

Total loads and storm-runoff loads were determined for total suspended solids, chemical oxygen demand, total organic carbon, and selected nutrients and metals. Runoff loads were calculated in pounds and pounds per acre-inch of rainfall. Load data for storm runoff and total runoff also are presented as event mean concentrations, in milligrams per liter and micrograms per liter.

Storm runoff to the South Platte River increased the volume of flow at the 50th Avenue gaging station to nearly three times the base flow. The increase in main-stem storm-runoff loads was from 2.6 times the base-flow load (total orthophosphate) to nearly 30 times the base-flow load (total suspended solids). Total runoff from the tributaries ranged from 680,000 to 5.2 million cubic feet, and storm runoff ranged from 640,000 to 4.2 million cubic feet. Total runoff for the study area was 60 million cubic feet (approximately 1,400 acre-feet), and storm runoff was 39 million cubic feet (approximately 900 acre-feet).

Storm-runoff loads also were computed for the tributaries. Total suspended solids ranged from 32,000 to 1.4 million pounds, chemical oxygen demand ranged from 10,000 to 120,000 pounds, total phosphorus ranged from 37 to 1,100 pounds, and total lead ranged from 25 to 300 pounds. Storm-runoff loads for the same constituents for the entire study area were 6.9 million pounds for total suspended solids, 840,000 pounds for chemical oxygen demand, 9,100 pounds for total phosphorus, and 1,200 pounds for total lead. Additional nutrients and metals monitored include total organic carbon, total nitrite plus nitrate, total Kjeldahl nitrogen, total orthophosphate, total copper, total manganese, and total zinc (total nitrogen was calculated by adding total Kjeldahl and total nitrite plus nitrate).

At two stations monitored on the South Platte River, the event mean concentrations of copper and zinc exceeded water-quality standards for aquatic life in effect in Colorado. Lead concentrations exceeded proposed standards for aquatic life at all stations, and manganese concentrations exceeded them at six stations.

An analysis of cumulative tributary stormload versus main-stem stormloads indicates that a substantial part of the load in the South Platte River is resuspended bottom material, if the unmonitored area can be assumed to contribute the same proportion of storm-runoff load as the monitored area. The magnitude of the constituent loads from possible bottom scour of the South Platte River based on data from the 19th Street gage in Denver could be as much as 40 percent of the total suspended solids, 50 percent of the total phosphorus, and 6 percent of the total lead.

The analysis also indicates that a detention structure on a major tributary may significantly decrease storm-runoff loads. A comparison of storm-runoff loads from two adjacent tributaries, Sanderson Gulch and Weir Gulch, which have nearly equal total and effective impervious areas, seems to support this possibility. The basin with a detention structure had significantly smaller storm-runoff loads.

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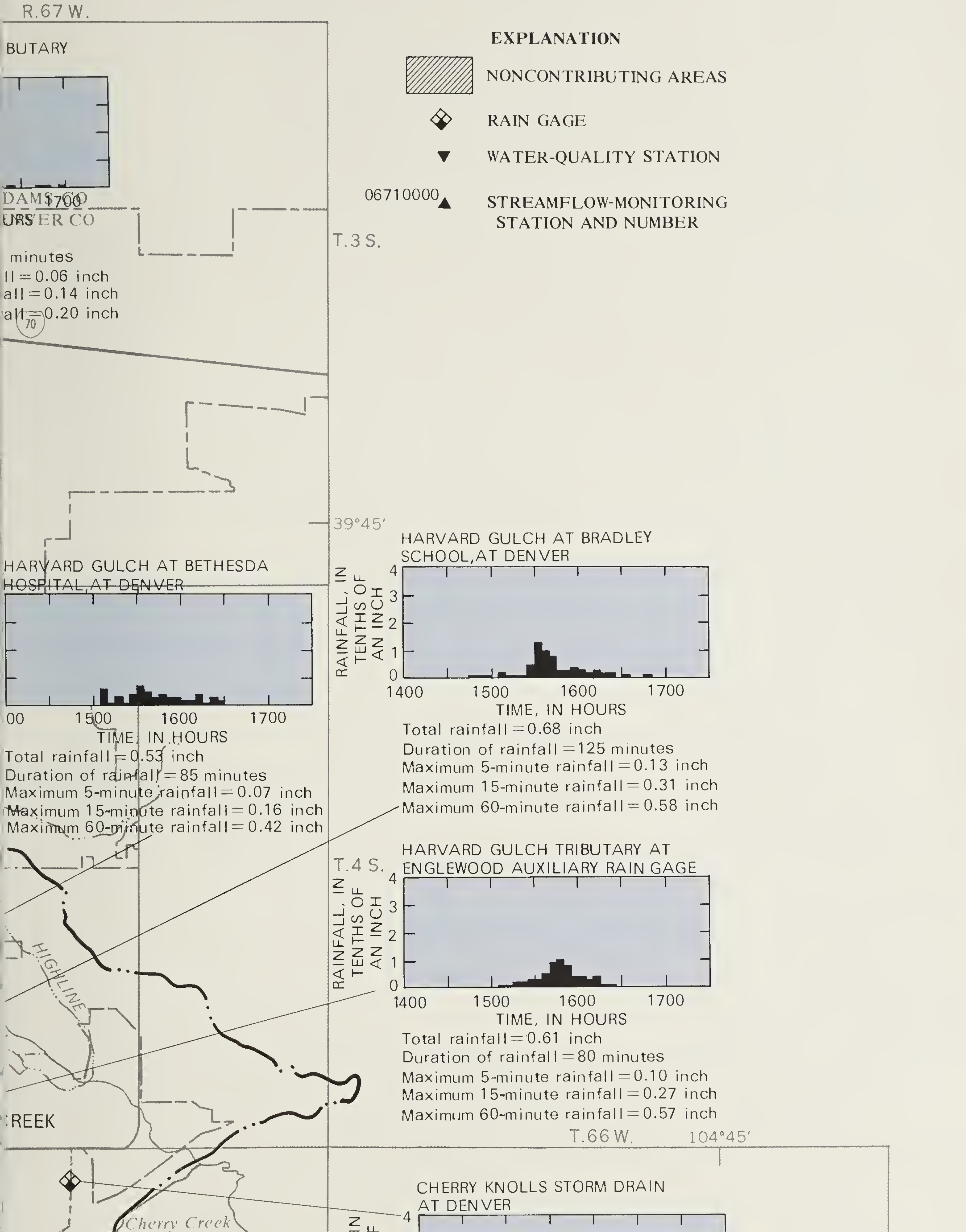
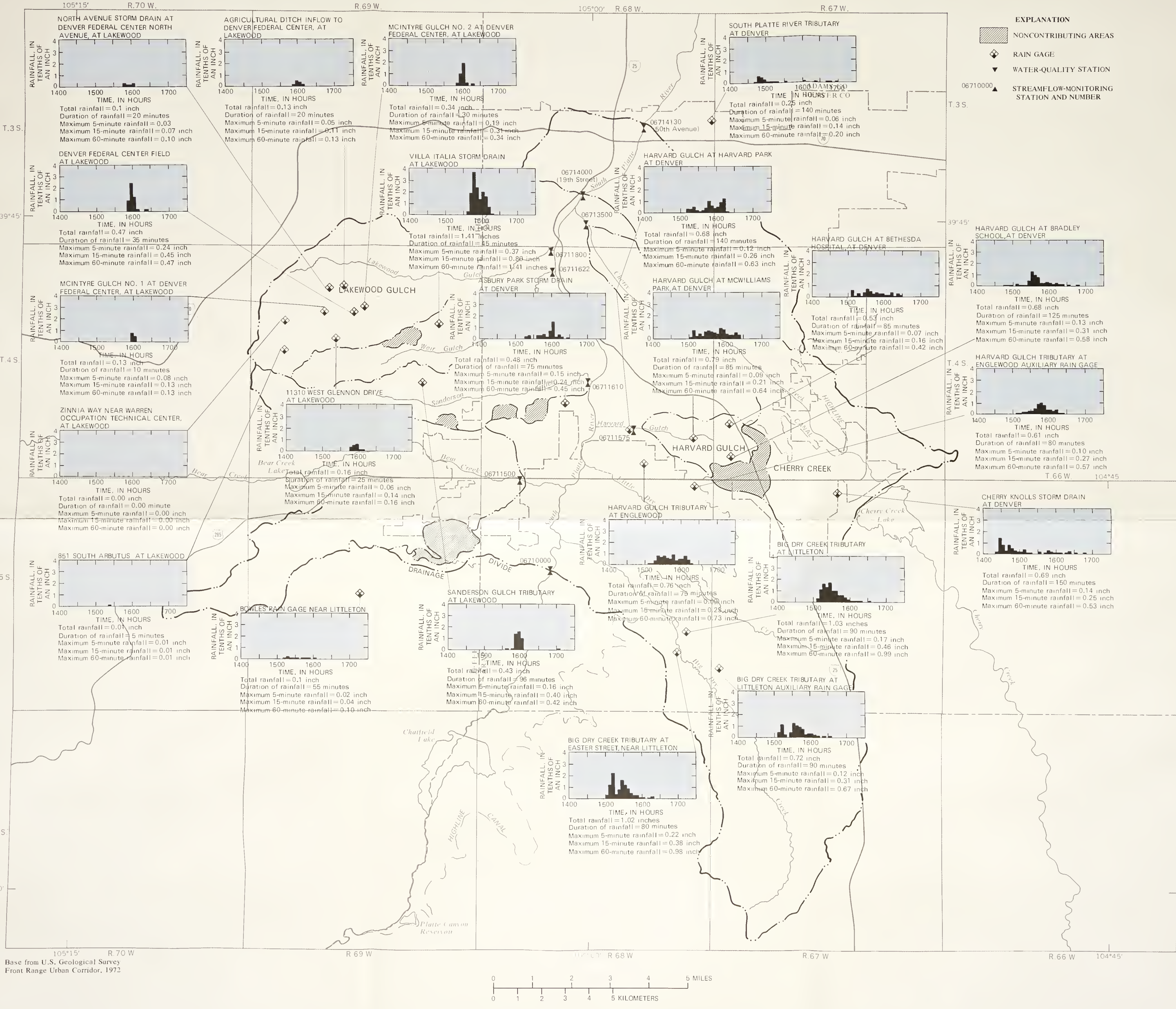

R.67 W.
BUTARY
DAMS CO
ER CO
1700
minutes
ll = 0.06 inch
all = 0.14 inch
all = 0.20 inch
70
EXPLANATION
NONCONTRIBUTING AREAS
RAIN GAGE
WATER-QUALITY STATION
06710000
STREAMFLOW-MONITORING STATION AND NUMBER
T.3 S.
39°45′
HARVARD GULCH AT BETHESDA HOSPITAL, AT DENVER
00
1500
1600
1700
TIME, IN HOURS
Total rainfall = 0.53 inch
Duration of rainfall = 85 minutes
Maximum 5-minute rainfall = 0.07 inch
Maximum 15-minute rainfall = 0.16 inch
Maximum 60-minute rainfall = 0.42 inch
HARVARD GULCH AT BRADLEY SCHOOL, AT DENVER
RAINFALL, IN TENTHS OF AN INCH
4
3
2
1
0
1400
1500
1600
1700
TIME, IN HOURS
Total rainfall = 0.68 inch
Duration of rainfall = 125 minutes
Maximum 5-minute rainfall = 0.13 inch
Maximum 15-minute rainfall = 0.31 inch
Maximum 60-minute rainfall = 0.58 inch
T.4 S.
HARVARD GULCH TRIBUTARY AT ENGLEWOOD AUXILIARY RAIN GAGE
RAINFALL, IN TENTHS OF AN INCH
4
3
2
1
0
1400
1500
1600
1700
TIME, IN HOURS
Total rainfall = 0.61 inch
Duration of rainfall = 80 minutes
Maximum 5-minute rainfall = 0.10 inch
Maximum 15-minute rainfall = 0.27 inch
Maximum 60-minute rainfall = 0.57 inch
HIGHLINE
REEK
T.66 W.
104°45′
CHERRY KNOLLS STORM DRAIN AT DENVER
4
Cherry Creek

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

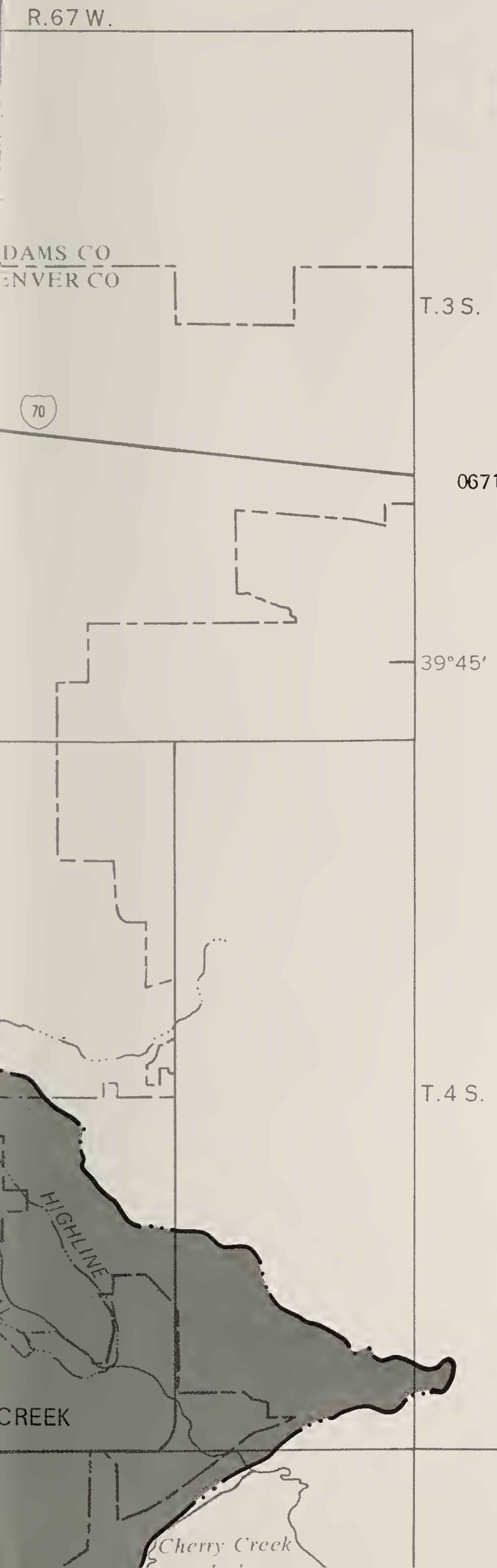
Prepared in cooperation with the
DENVER REGIONAL COUNCIL OF GOVERNMENTS

WATER-RESOURCES INVESTIGATIONS REPORT 83-4138
PLATE 1



Base from U.S. Geological Survey
Front Range Urban Corridor, 1972

MAP SHOWING LOCATION OF RAIN GAGES, WATER-QUALITY AND STREAMFLOW-MONITORING STATIONS, DRAINAGE BASINS AND NONCONTRIBUTING AREAS, AND RAINFALL DATA AT RAIN GAGES FOR STORM OF AUGUST 14, 1980, SOUTHERN DENVER METROPOLITAN AREA, COLORADO



EXPLANATION

MONITORED TRIBUTARY BASINS

NONCONTRIBUTING AREA WITHIN MONITORED TRIBUTARY BASINS

UNMONITORED DRAINAGE AREA BETWEEN THE SOUTH PLATTE RIVER AT LITTLETON AND THE SOUTH PLATTE RIVER AT 19TH STREET

UNMONITORED DRAINAGE AREA BETWEEN THE SOUTH PLATTE RIVER AT 19TH STREET AND THE SOUTH PLATTE RIVER AT 50TH AVENUE

▼ WATER-QUALITY STATION

06710000▲ STREAMFLOW-MONITORING STATION AND NUMBER

SUMMARY OF BASIC DATA

LAKEWOOD GULCH
- Basin rainfall = 0.22 inch
- Basin storm runoff = 640,000 cubic feet
- Basin area = 10,400 acres

WEIR GULCH
- Basin rainfall = 0.28 inch
- Basin storm runoff = 920,000 cubic feet
- Basin area = 4790 acres

SANDERSON GULCH
- Basin rainfall = 0.32 inch
- Basin storm runoff = 1,300,000 cubic feet
- Basin area = 4720 acres

BEAR CREEK
- Basin rainfall = 0.31 inch
- Basin storm runoff = 2,700,000 cubic feet
- Basin area = 15,400 acres

CHERRY CREEK
- Basin rainfall = 0.29 inch
- Basin storm runoff = 4,200,000 cubic feet
- Basin area = 15,800 acres

HARVARD GULCH
- Basin rainfall = 0.35 inch
- Basin storm runoff = 1,200,000 cubic feet
- Basin area = 2000 acres

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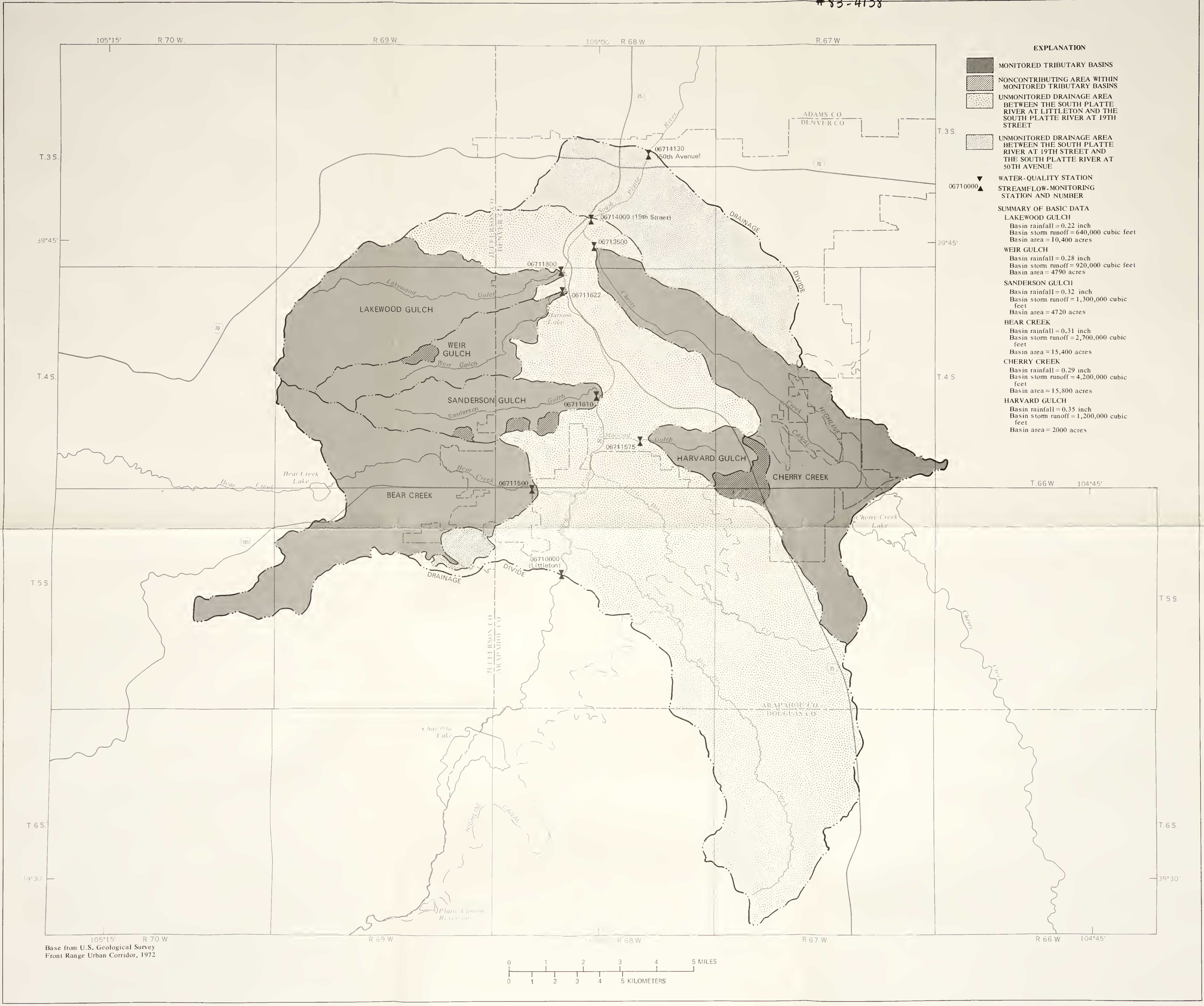
WATER-RESOURCES INVESTIGATIONS REPORT 83-4138
PLATE 2



MAP SHOWING LOCATION AND AREA OF MONITORED TRIBUTARY BASINS, NONCONTRIBUTING AREAS WITHIN MONITORED TRIBUTARY BASINS, UNMONITORED DRAINAGE AREAS, AND BASIN RAINFALL AND RUNOFF FOR THE STORM OF AUGUST 14, 1980, SOUTHERN DENVER METROPOLITAN AREA, COLORADO

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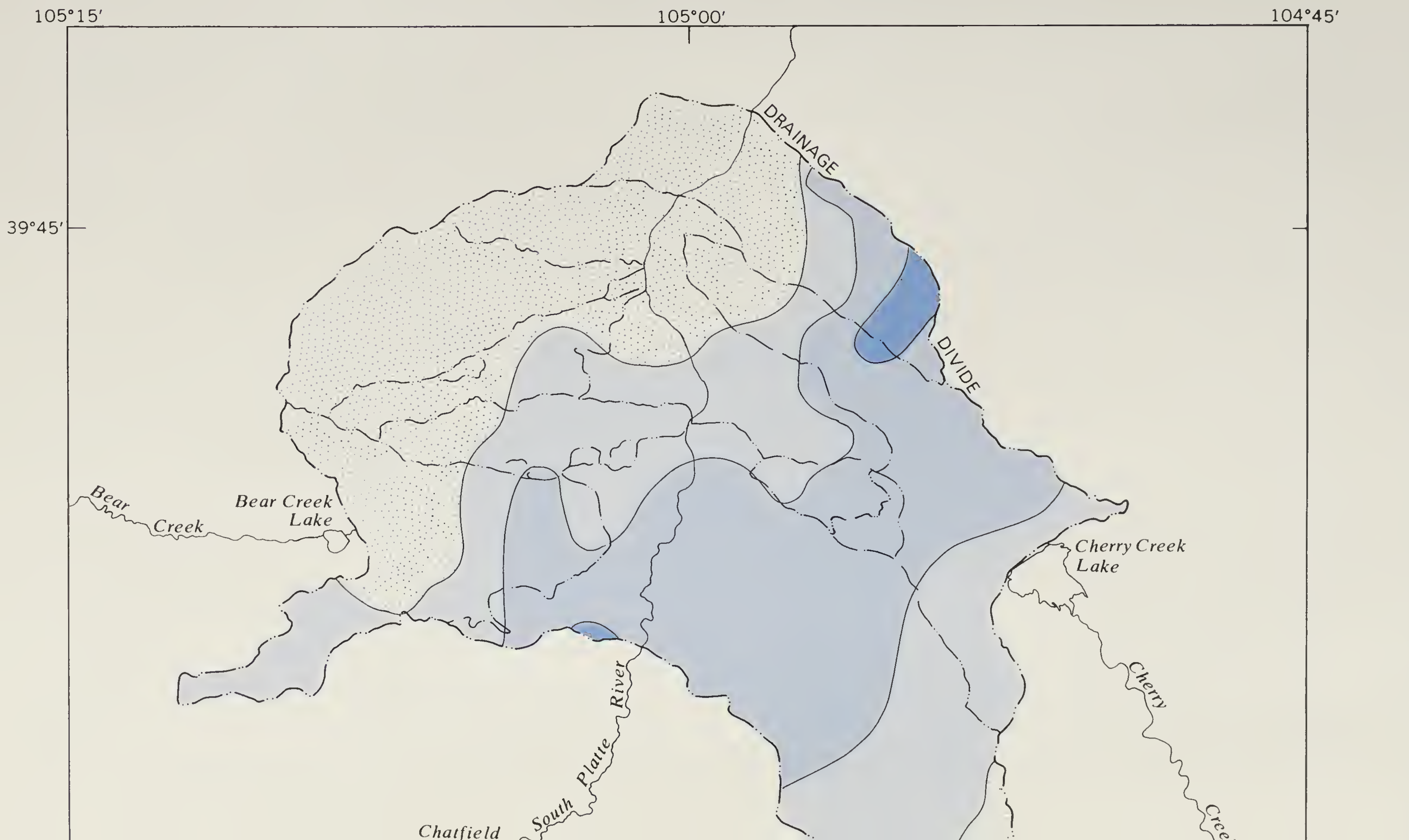

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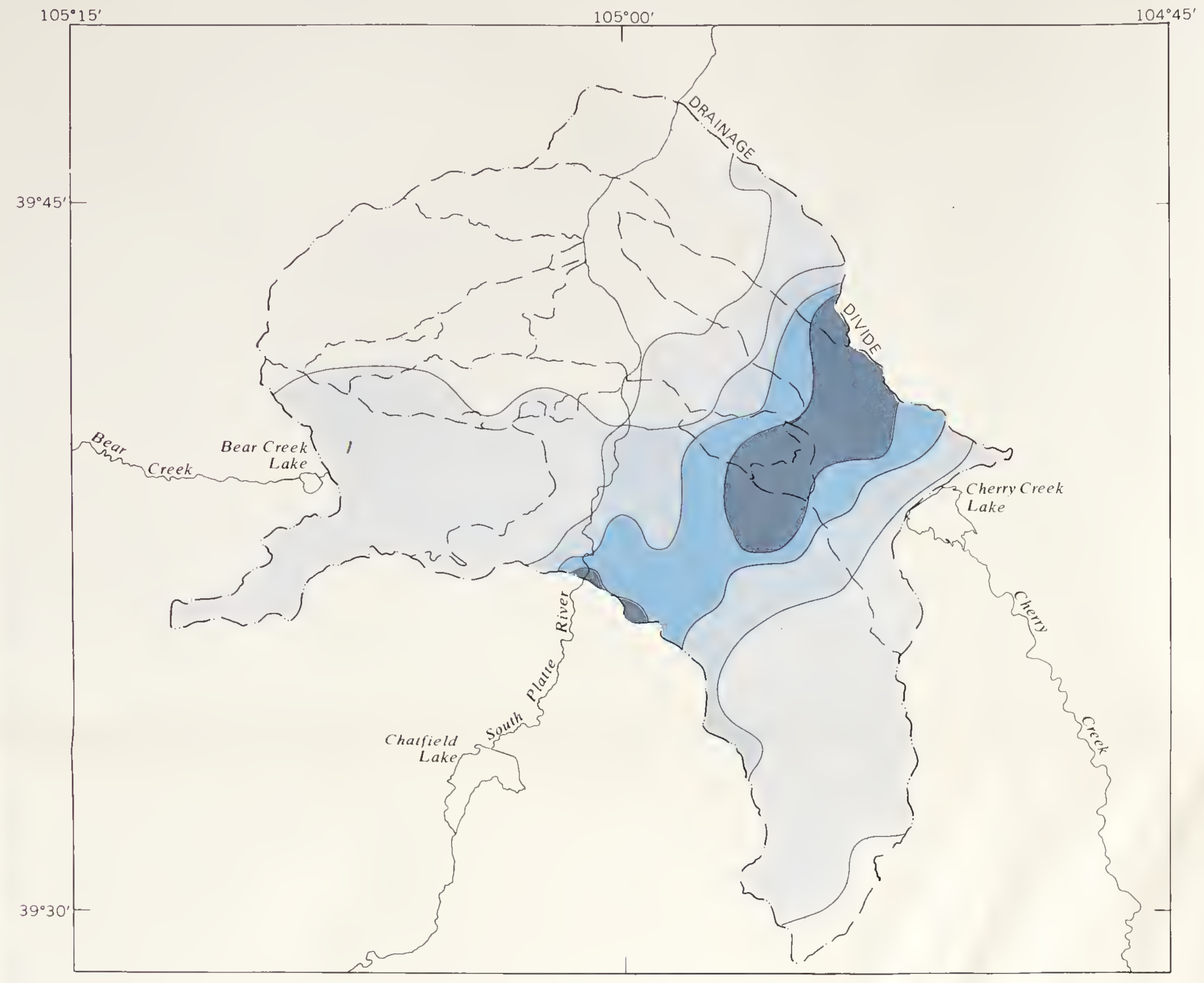
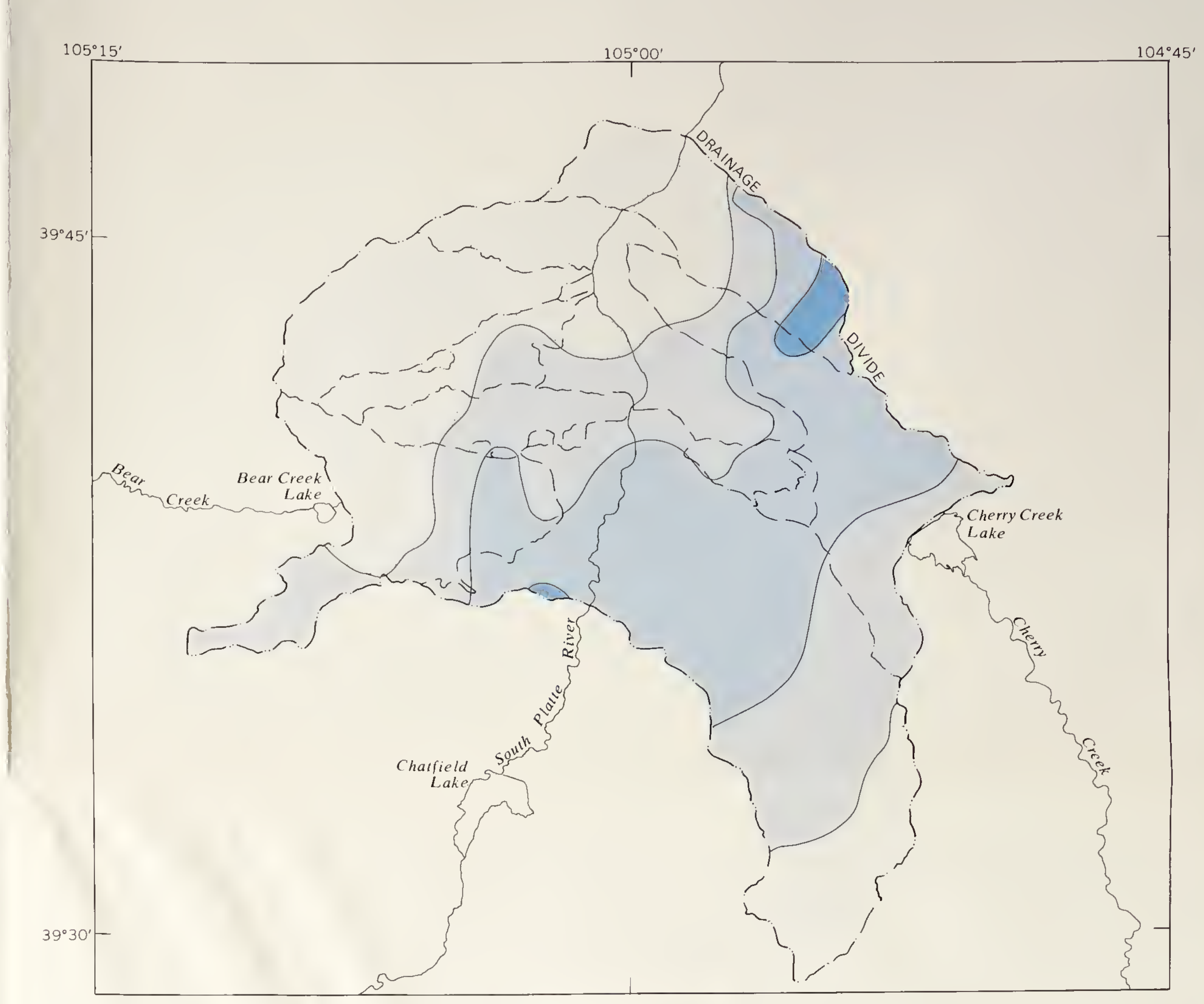
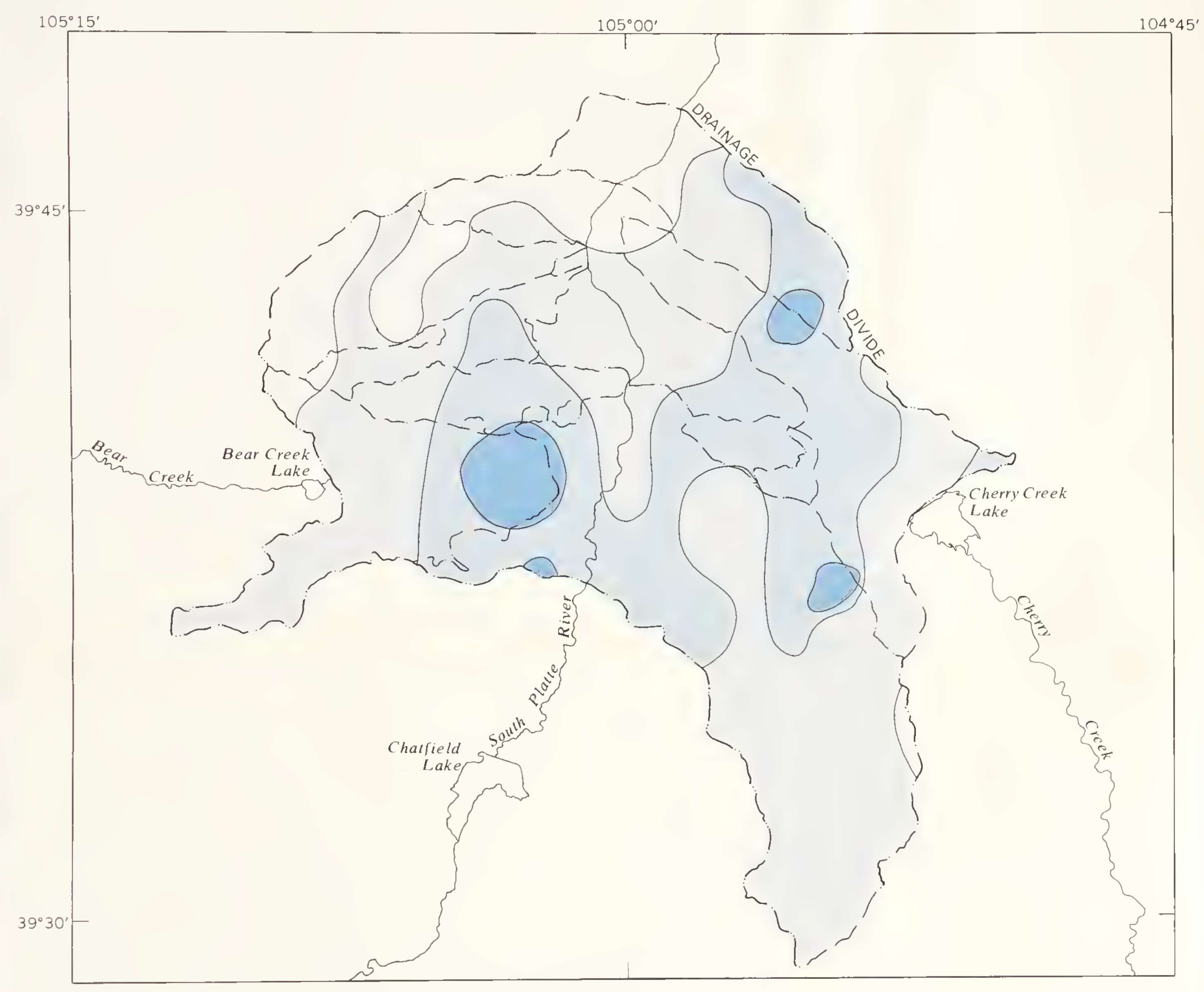


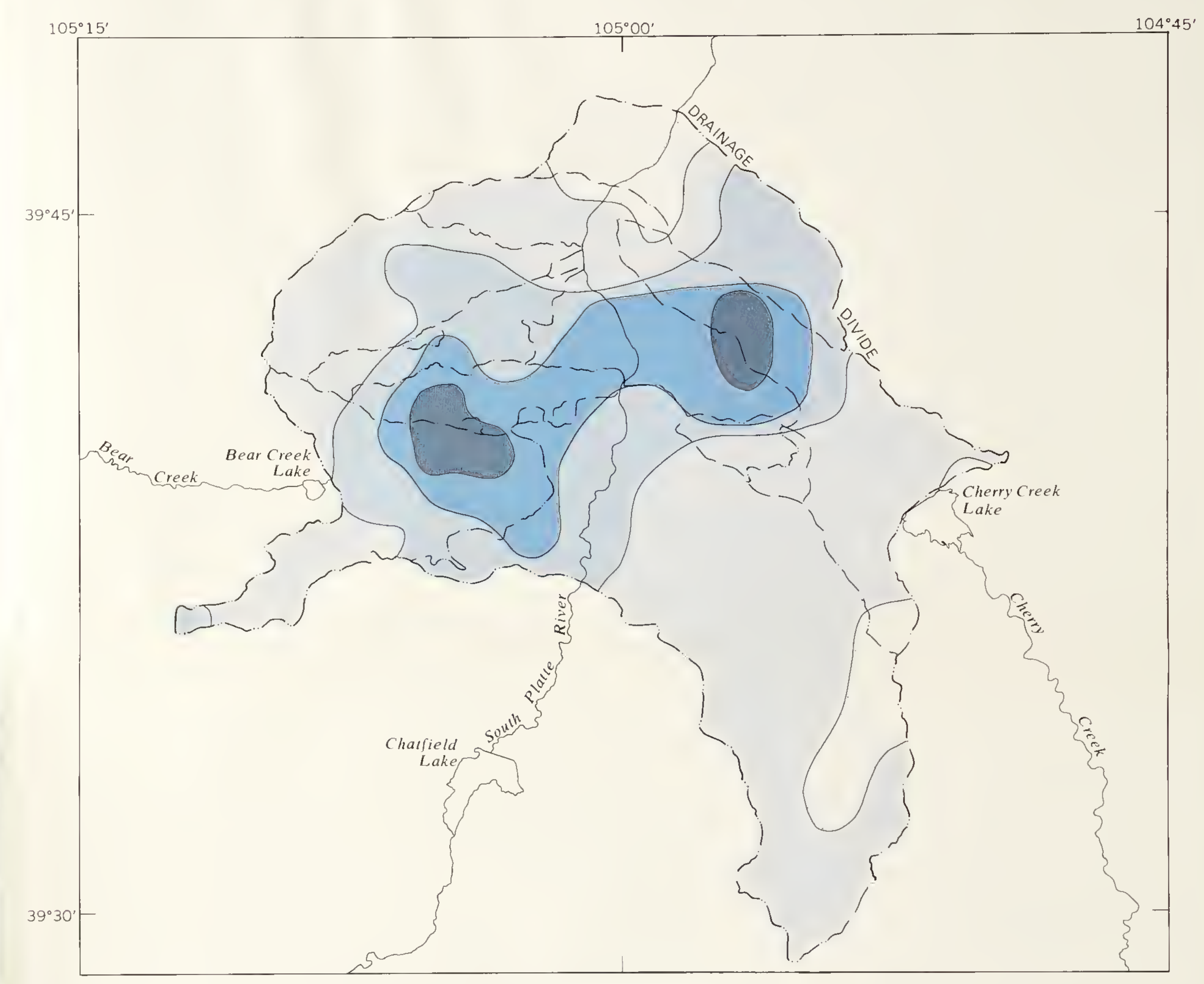
1400–1415 HOURS



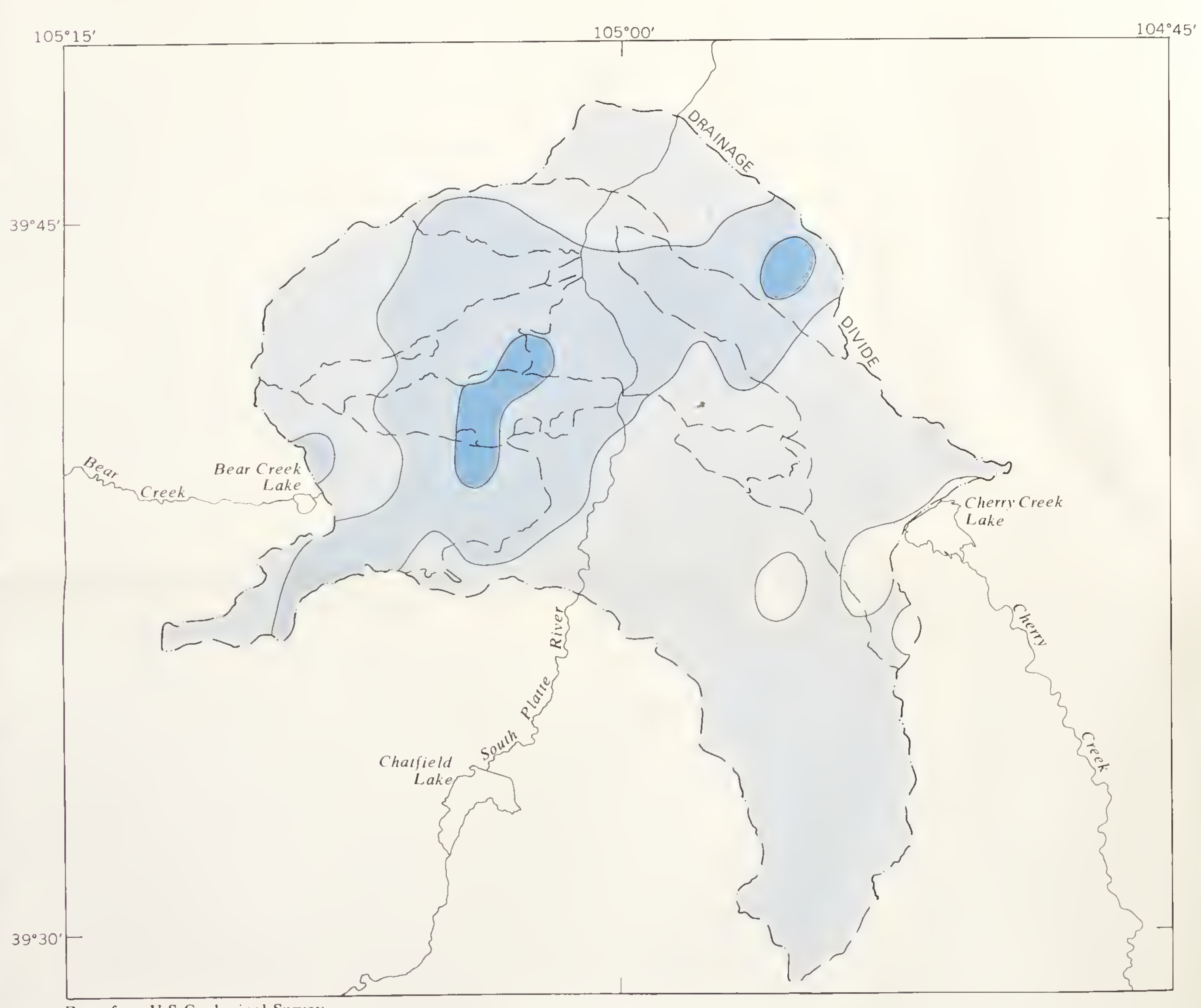
1415–1430 HOURS



1430–1445 HOURS

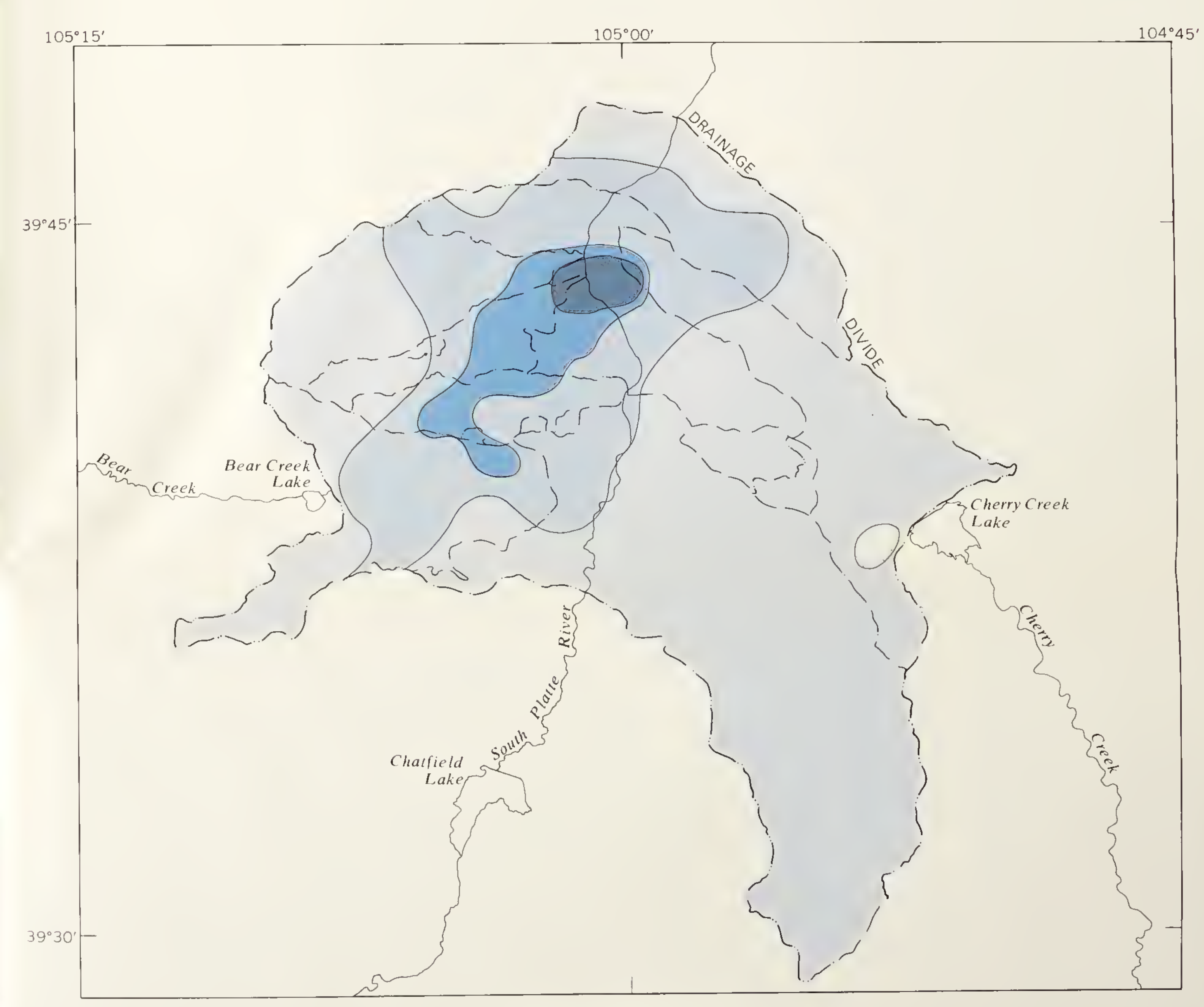


1445–1500 HOURS

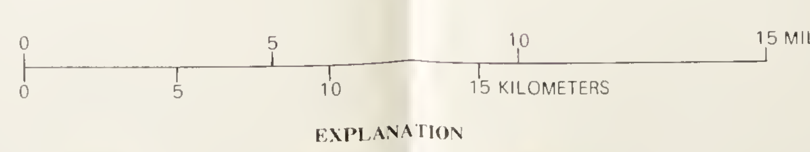


Base from U.S Geological Survey
Front Range Urban Corridor, 1972

1500–1515 HOURS



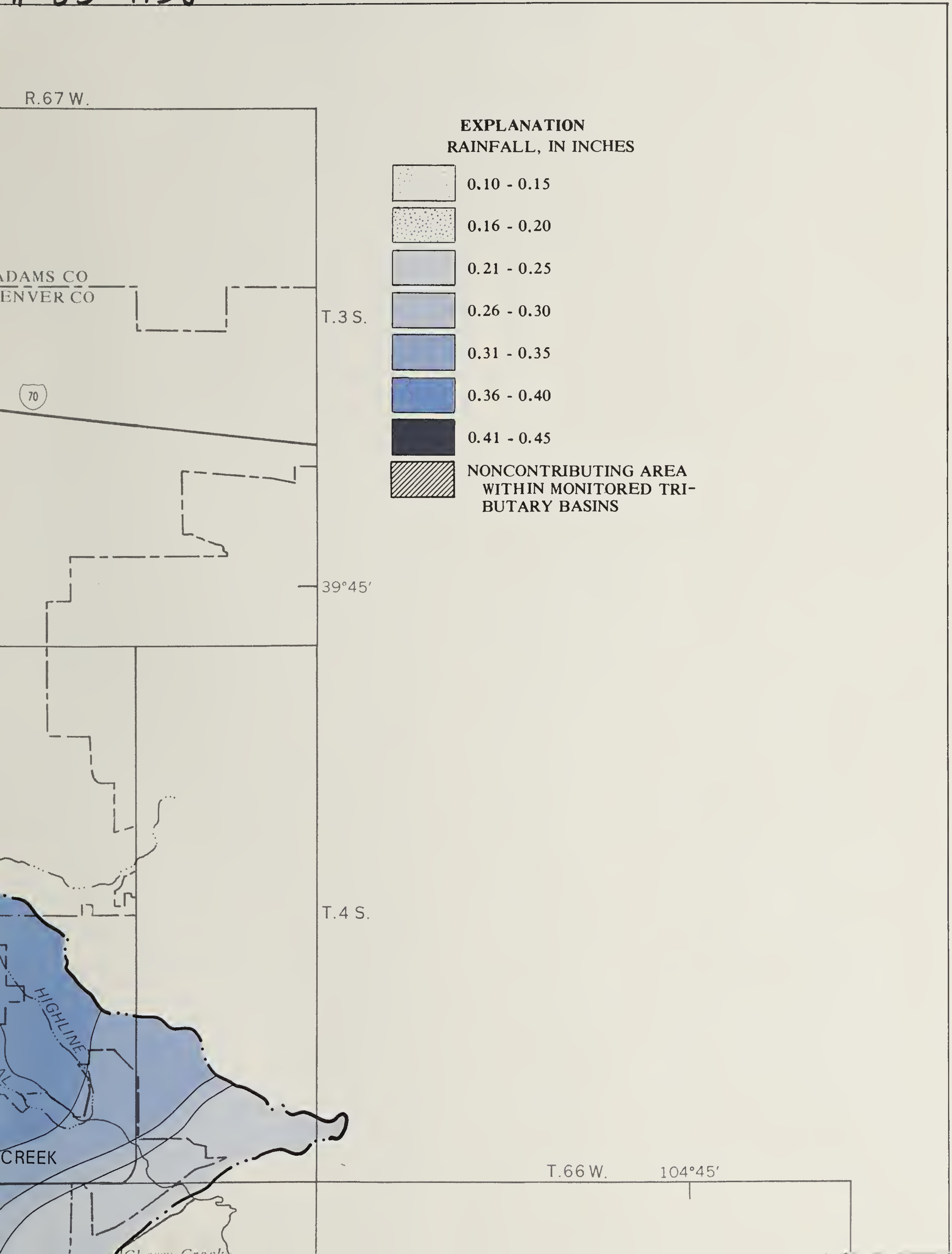
1515–1530 HOURS



EXPLANATION
RAINFALL, IN INCHES

0.00 - 0.02
0.02 - 0.04
0.04 - 0.06
0.06 - 0.08
0.08 - 0.10

PRECIPITATION MAPS BASED ON RADAR-SIMULATED RAINFALL DATA REPRESENTING SIX CONSECUTIVE 15-MINUTE INTERVALS FROM 1400-1530 HOURS ON AUGUST 14, 1980, SOUTHERN DENVER METROPOLITAN AREA, COLORADO


R.67 W.
EXPLANATION
RAINFALL, IN INCHES
0.10 - 0.15
0.16 - 0.20
0.21 - 0.25
0.26 - 0.30
0.31 - 0.35
0.36 - 0.40
0.41 - 0.45
NONCONTRIBUTING AREA WITHIN MONITORED TRIBUTARY BASINS
ADAMS CO
ENVER CO
T.3 S.
70
39°45′
T.4 S.
HIGHLINE
CREEK
T.66 W.
104°45′

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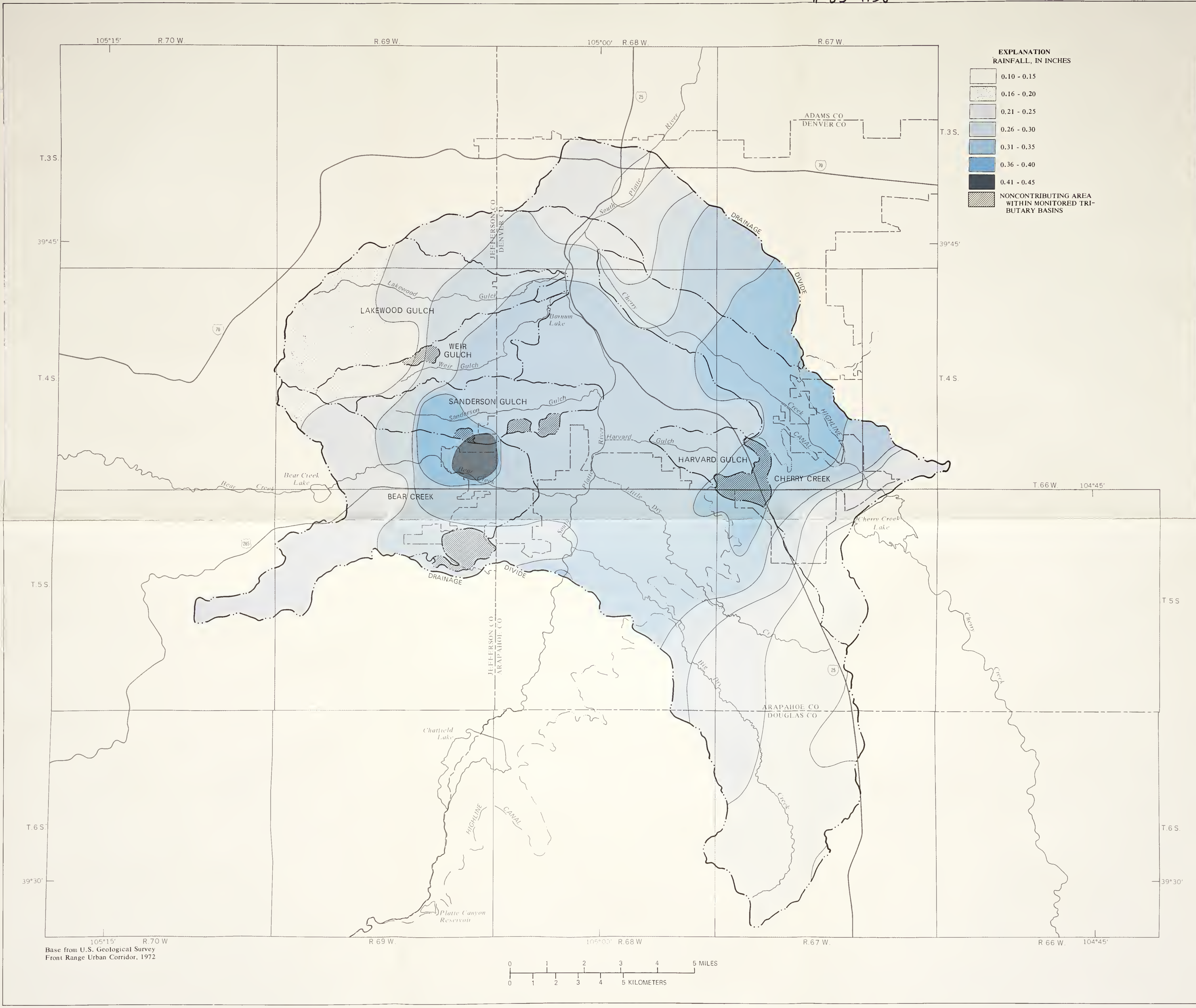
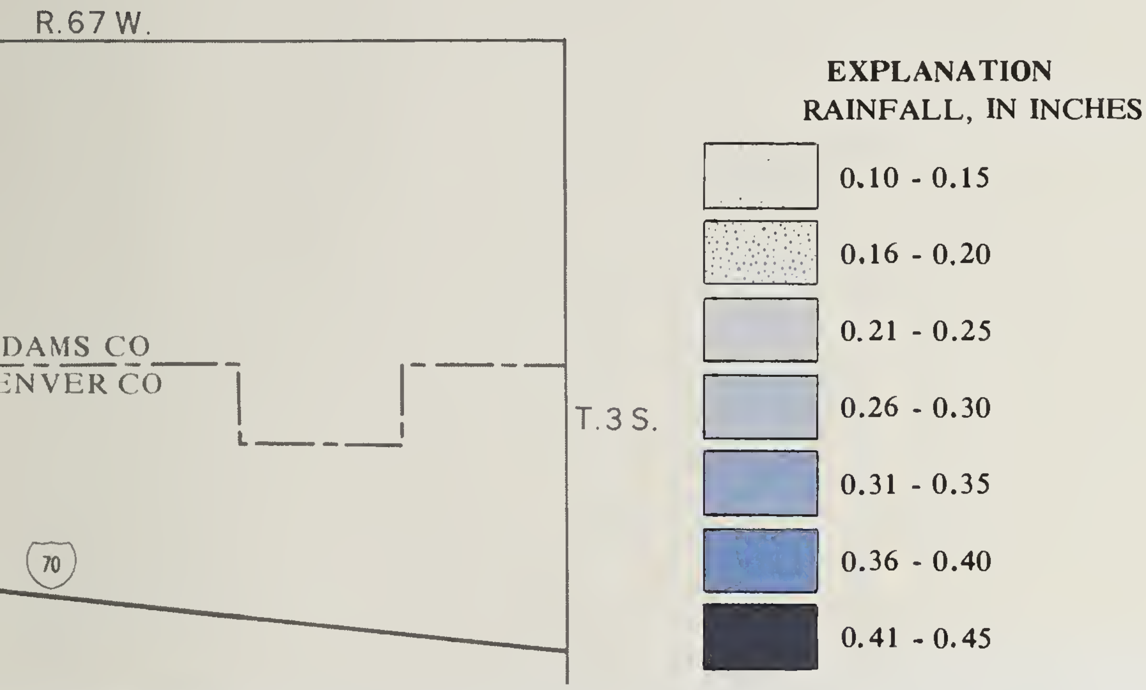


PRECIPITATION MAP BASED ON RADAR-SIMULATED RAINFALL DATA FOR 1330-1630 HOURS, AUGUST 14, 1980, SOUTHERN DENVER METROPOLITAN AREA, COLORADO


R.67 W.
DAMS CO
ENVER CO
T.3 S.
70
EXPLANATION
RAINFALL, IN INCHES
0.10 - 0.15
0.16 - 0.20
0.21 - 0.25
0.26 - 0.30
0.31 - 0.35
0.36 - 0.40
0.41 - 0.45

Blakely, Mu rd, and Doerfer--ANALYSIS OF